

**United States Military Academy
West Point, New York 10996**

Imagery Enhancement to the Disposable, Air-droppable, Meteorological Tower Array (DAMTA)

**OPERATIONS RESEARCH CENTER OF EXCELLENCE
TECHNICAL REPORT: DSE-TR-03-01**

Prepared for:

- * University Partnering for Operational Support (UPOS)**
- * Army Research Laboratories (ARL), and**
- * Applied Technologies Incorporated (ATI)**

By The: DEPARTMENT OF SYSTEMS ENGINEERING

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01 JUNE 2003

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14. ABSTRACT The Army Research Laboratory (ARL), Computational and Information Sciences Directorate, Battlefield Environment Division, at White Sands Missile Range (WSMR), New Mexico is currently involved in overseeing the development of a new battlefield weather information resource. This new resource deemed DAMTA (Disposable, Air-droppable, Meteorological Tower Array) will consist of multiple individual towers, which will be dispersed over selected battlefield locations by an airborne platform. They will collect and transmit meteorological data in unattended operation for up to 30 days. The purpose of this current research project is to investigate the benefits of augmenting the DAMTA with digital imagery sensors to collect near real-time images of weather conditions on the battlefield. The mission of this project was to provide a detailed recommendation for imagery enhancement to the DAMTA platform. The specific deliverables were as follows: 1) To determine the benefits that will accrue to the army through the use of imagery enhanced DAMTA; 2) to determine a specific off-the-shelf camera most suited to integration with the DAMTA; 3) to construct a prototype demonstrating the best method of integrating cameras with the DAMTA platform.					
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Abstract

Imagery Enhancement to the Disposable, Air-droppable, Meteorological Tower Array

United States Military Academy (USMA)

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The Army Research Laboratory (ARL), Computational and Information Sciences Directorate, Battlefield Environment Division, at White Sands Missile Range (WSMR), New Mexico is currently involved in overseeing the development of a new battlefield weather information resource. This new resource deemed DAMTA (Disposable, Air-droppable, Meteorological Tower Array) will consist of multiple individual towers, which will be dispersed over selected battlefield locations by an airborne platform. They will collect and transmit meteorological data in unattended operation for up to 30 days. Currently, the DAMTA platform prototype is being developed by Applied Technology Incorporated (ATI) in Longmont, CO as Phase II of a Small Business Initiatives for Research (SBIR) project under the auspices of ARL-WSMR. They received \$750K for this initiative.

The purpose of this current research project is to investigate the benefits of augmenting the DAMTA with digital imagery sensors to collect near real-time images of weather conditions on the battlefield. The DAMTA project encourages the use of off-the-shelf technology. Digital imagery in particular is the focus of this proposal as it provides valuable information not available through other sensors and yet highly desirable on the battlefield. Funding in the amount of \$100K was provided by University Partnering for Operational Support (UPOS). ARL provided oversight and guidance for the project. The study commenced in June 2002 and was completed in May 2003 meeting the 1 June 2003 UPOS requirement.

The mission of this project was to provide a detailed recommendation for imagery enhancement to the DAMTA platform. The specific deliverables were as follows: 1) To determine the benefits that will accrue to the army through the use of an imagery enhanced DAMTA; 2) to determine a specific off-the-shelf camera most suited to integration with the DAMTA; 3) to construct a prototype demonstrating the best method of integrating cameras with the DAMTA platform. Each of these deliverables has been met. This study has been rewarding and revealing. The results are being provided to ARL, to UPOS and to ATI.

The team concluded that imagery can have a profound affect on accurately forecasting weather; visualizing and verifying raw weather data, and enhancing the commander's knowledge about the tactical situation on the battlefield. Imagery provides increased situational awareness for commanders and staffs within specific environments. Imagery will reduce loss of life during tactical operations by minimizing mission failures, and providing the opportunity to plan and execute missions better than with only raw weather data. The DAMTA platform with integrated imagery will reduce costs for: 1) equipment in terms of dollars and wear and tear consequently decreasing the mean time to failure of components; 2) personnel in terms of lives, dollars, and time consequently increase efficiency, forecasting and battlefield

superiority and 3) mission failures in terms of operational momentum and time to complete objectives. Section 6 addresses these benefits in detail.

The research team recommends the use of the Micro Video MVC 3200 C Pinhole camera for this application. This camera is available through Micro Video at www.microvideo.ca. These cameras cost approximately \$239.00. Bulk costs will be less than \$200 each. Section 7 provides a justification for this choice.

The team concluded that three small fixed MVC 3200 C pinhole cameras spaced 120 degrees apart near the top of the DAMTA platform are ideal. This configuration provides the best possible view, provides adequate coverage of the horizon, and optimizes the placement of sensors and electronics at the top of the platform. Section 8 provides a full explanation of this conclusion.

Table of Contents

ABSTRACT	i
Table of Contents	iii
List of Figures	v
List of Tables	
1. Overview	1
1.1 Brief Description of the Problem	1
1.2 Project Deliverables	1
1.3 Major Project Milestones	2
1.4 Expected Profitability	2
1.5 Probable Technical Results of the Project	2
2. Project Background	4
3. Project Mission and Deliverables	8
3.1 Mission Statement	8
3.2 Deliverables	8
4. General Approach	9
4.1 Managerial Approach	9
4.2 Technical Approach	10
4.3 Supporting Organizations	11
4.4 Contractual Aspects	11
4.5 Schedules	12
4.6 Resource Requirements	12
4.7 Personnel	12
4.8 Facility Support	13
4.9 Issues Resolved	13
5. Problem Definition	15
5.1 Needs Analysis	15
5.2 Stakeholder Analysis	15
5.3 Functional Analysis	18
5.4 Value System Modeling	22
6. Systems Integration	25
6.1 Imagery Benefits	26
6.1.1 Imagery Benefits Online Survey and Results	27
6.1.2 Analysis of Results	39
6.2 Methods of Employment	56
6.3 Risks and Vulnerabilities	60
7. Hardware Selection	64
7.1 Alternatives Generation	64
7.1.1 Development of Alternatives	64
7.1.2 Purchasing	70
7.2 Testing	70
7.2.1 Home Base Test and Preparation	70

7.2.2 Cold Weather Test	71
7.2.3 Hot/Tropical Weather Test	78
7.2.4 Temperate Weather Test	86
7.2.5 Shock Test	88
7.3 Camera Selection	89
7.3.1 Final Feasibility Screening	90
7.3.2 Multi-Objective Decision Analysis	90
8. Hardware Integration with DAMTA Platform	98
9. Conclusions and Recommendations	104
<i>References</i>	106
<i>Appendix A – Project Schedule</i>	107
<i>Appendix B – Survey</i>	112
<i>Appendix C – Cold Test Plan</i>	117
<i>Appendix D – Hot/Tropical Test Plan</i>	122
<i>Appendix E – Compact Disk (CD) Information</i>	129

List of Figures

Figure 2.1 – Five functions of DAMTA platform	5
Figure 2.2 – Initial prototype DAMTA produced by USMA Research Team	6
Figure 2.3 – Prototype of DAMTA platform produced by ATI	6
Figure 5.1 - Weather Analysis on the Battlefield	16
Figure 5.2 - DAMTA Functional Hierarchy	19
Figure 5.3 - DAMTA Value Hierarchy	23
Figure 6.1 - Question 1 Open Responses Summary Diagram	29
Figure 6.2 - Question 2 Open Responses Summary Diagram	30
Figure 6.3 - Question 9 Open Responses Summary Diagram	36
Figure 6.4 - Weather Information Sources used by Respondents (Question 1)	39
Figure 6.5 - Weather Information Sources used by Army Branches (Question 1)	39
Figure 6.6 - Most Important Weather Data for users (Question 2)	40
Figure 6.7 - Second Most Important Weather Data for users (Question 2)	40
Figure 6.8 - Battlefield Functions selected by Respondents {Importance from left to right} (Question 3)	41
Figure 6.9 - Battlefield Functions selected by Branch (Question 3)	42
Figure 6.10 - Weather Information Chart (Question 4)	43
Figure 6.11 - Percent Responding to Weather Data Importance (Question 5)	44
Figure 6.12 - Imagery Device Capability Chart (Question 6, 7, 8)	45
Figure 6.13 - Score Line for Imagery Device Capabilities (Question 6, 7, 8)	45
Figure 6.14 - Imagery Device Policies Selection Chart (Question 10)	46
Figure 6.15 - Score Line for Imagery Device Policy (Question 11)	47
Figure 6.16 - Imagery Device Attributes Selection Chart (Question 11)	48
Figure 6.17 - Imagery Device Attributes Selection Chart by Branch (Question 11)	49
Figure 6.18 - Imagery Device Attributes Selection Area Chart by Branch (Question 11)	49
Figure 6.19 - Imagery Device Configuration Importance Average Chart (Question 12)	51
Figure 6.20 - Imagery Device Configuration Importance Bar Chart (Question 12)	51
Figure 6.21 - Imagery Device Percentage Selecting the three Configurations (Question 12)	52
Figure 6.22 - Histogram of Respondents Choices (Question 13)	53
Figure 6.23 - Order of Value of Imagery for Branches	54
Figure 6.24 - Histogram of Digital Imagery Update Timeline (Question 14)	55
Figure 6.25 - Impact on Success from Imagery Integration with a Weather Collection System	55

Figure 6.26 - DAMTA Affinity Diagram	56
Figure 6.27 - Helicopter Employment of DAMTA	59
Figure 7.1 - Cadet Green Preparing Cables for Cold Weather Test	72
Figure 7.2 – LTC Buckingham and Cadet Green in the Cold Chamber	73
Figure 7.3 – Data Collection Equipment Outside the Cold Chamber	74
Figure 7.4 – LTC Buckingham and Cadet Green Collecting Data During Cold Chamber Test	75
Figure 7.5 – Preparations for 30 Day Test at Bolio Lake	76
Figure 7.6 – Test Stands at Bolio Lake	76
Figure 7.7 – Quad Image of Live-Feed Video from Test Cameras in Alaska	77
Figure 7.8 – The eight cameras tested in Panama at the Hot/Tropical Test Site	80
Figure 7.9 – Hot/Tropical Test Site in Gamboa, Panama	81
Figure 7.10 – Monitoring Equipment at Test Site in Gamboa, Panama	82
Figure 7.11 - Cameras on test stands at initial location in Gamboa	82
Figure 7.12 - Cameras on test stands at final location in Gamboa	83
Figure 7.13 – Individual Snapshots from Each of 8 Cameras in Hot Test	85
Figure 7.14 – Cadet Chris Green with Cameras positioned for Temperate Climate Test	87
Figure 7.15 – Characteristic Pink Streaks in Image	88
Figure 7.16 – Cameras being positioned for Shock Test at Various Heights	89
Figure 7.17 – Utility Curves: Field of View, Lux Rating, and Weight	94
Figure 7.18 – Multi-Objective Decision Analysis Matrix	94
Figure 7.19 – MODA Scores versus the Cost of Each Individual Camera	95
Figure 7.20 – MVC 3200 C Pinhole Camera	97
Figure 8.1 – Original DAMTA Model Produced at USMA – Spring 2002	99
Figure 8.2 – DAMTA Prototype Produced by ATI – Fall 2002	99
Figure 8.3 – Initial 3D Drawings of Imagery Module	100
Figure 8.4 – Plastic Prototype of Modular Imagery Enhancement to DAMTA	101
Figure 8.5 – DAMTA Model with Imagery Enhancement – Full View	102
Figure 8.6 – Top of DAMTA “Can” Showing Camera Placement	102
Figure 8.7 – DAMTA “Can” with MVC 3200 C Pinhole Camera Port	103

List of Tables

Table 1 – Milestone List for Project	2
Table 4.1 – Linear Responsibility Chart	9
Table 4.2 – Supporting Organizations	11
Table 4.3 – Budget Categories	12
Table 5.1 - Stakeholder Table	17
Table 5.2 - Functional Definition Table	20
Table 5.3 - Sub-function Definition Table	21
Table 5.4 - DAMTA Attribute Relationships	23
Table 5.5 - DAMTA Attribute Tradeoffs	23
Table 6.1 - DAMTA Project Management Scheme	26
Table 6.2 - DAMTA Survey Demographics (U.S. Army Branch)	28
Table 6.3 - DAMTA Survey Demographics (Rank/Grade)	28
Table 6.4 - DAMTA Survey Question 1 and Results	28
Table 6.5 - DAMTA Survey Question 2 and Results	29
Table 6.6 - DAMTA Survey Question 3 and Results	31
Table 6.7 - DAMTA Survey Questions 4-8 and Results	32
Table 6.8 - DAMTA Survey Questions 10-11 and Results	33
Table 6.9 - DAMTA Survey Questions 12-15 and Results	34
Table 6.10 - DAMTA Survey Questions 9, 16 and 17 and Results	35
Table 6.11 – Question 16 Results (Truncated)	37
Table 6.12 - Question 17 Results (Truncated)	38
Table 6.13 - Selection Rate by Branch for 3 Camera Control Attributes	45
Table 6.14 - Selection Rate by Branch for 3 Control Policies	47
Table 6.15 – Level of Attribute Importance	49
Table 6.16 – Branch Average Value Level	52
Table 6.17 - Methods of Sensor Employment	58
Table 6.18 - Sensor Emplacement Consideration Definitions	59
Table 6.19 - Environmental Factor Descriptions	61
Table 6.20 - Vulnerability Descriptions	62
Table 6.21 - Environmental Factor Descriptions	63
Table 6.22 - Environmental Factor Descriptions (Continued)	63
Table 7.1 - Initial Feasibility Screen	67

Table 7.2 – Final Camera Feasibility Matrix	69
Table 7.3 – Sample Climate Data	84
Table 7.4 – Raw Data Matrix	92
Table 7.5 – Scoring Tables: Cold Test, Temperate Test, Hot Test	92
Table 7.6 – Scoring Charts: Dimensions and Weatherability	93
Table 7.7 – Tabulated Values from Sensitivity Analysis	96

Section 1 - Overview

1.1 Problem Description. The Army Research Laboratory (ARL), Computational and Information Sciences Directorate, Battlefield Environment Division, at White Sands Missile Range (WSMR), New Mexico is currently involved in overseeing the development of a new battlefield intelligence gathering resource. The purpose of this effort is to provide the Army with a capability to gather meteorological data from battlefield areas that lack weather collection resources. This data is required in order to enhance the accuracy of the Battlescale Forecast Model, as used in the Integrated Meteorological System (IMETS). The IMETS is the provider of meteorological information for the fielded Army.

This new resource, deemed DAMTA (Disposable, Air-droppable, Meteorological Tower Array) will consist of multiple individual meteorological towers, which will be dispersed over selected battlefield locations by an airborne platform. The towers will be capable of self-erecting to the vertical after being dropped from a moving aircraft at no less than 2000 feet and at speeds up to 120 knots. They will collect and transmit meteorological data in unattended operation for up to 30 days. These towers, once deployed, will communicate collected information to a central node (tower), which will in turn provide data to the IMETS and ultimately to the individual users.

Currently, the DAMTA platform prototype is being developed by Applied Technology Incorporated (ATI) in Longmont, CO as Phase II of an Small Business Initiatives for Research (SBIR) project under the auspices of ARL-WSMR. They received \$750K for this initiative.

The purpose of this current research project is to investigate the benefits of augmenting the DAMTA with digital imagery sensors to collect near real-time images of weather conditions on the battlefield. The DAMTA project encourages the use of off-the-shelf technology. Digital imagery in particular is the focus of this proposal as it provides valuable information not available through other sensors and yet highly desirable on the battlefield.

1.2 Project Deliverables. The mission of this project is to provide a detailed recommendation for imagery enhancement to the DAMTA platform. The specific deliverables are as follows:

- * A report documenting the findings of this research. Specifically it will enumerate:
 - ** Benefits to the Army of terrain-based, real-time, imagery collection to enhance intelligence gathering on the battlefield.
 - ** Recommended methods of employment of such a capability
 - ** An assessment of the risks and vulnerabilities of such a system deployed for tactical use in a remote, harsh, environment under varying geographical and climatic conditions
- * A recommendation of off-the-shelf imager sensor(s) currently available for this application

* Delivery of a physical prototype of the selected sensor as it might be employed on the DAMTA.

1.3 Major Project Milestones. Our major project milestones are shown in Table 1 below.

Table 1 – Milestone List for Project

Milestone	Date
Initial Research into hardware options	Jul-02
Data Mining/Literature Search	Sep-02
Initial hardware purchases	Oct-02
Construct Collaborative Website	Oct-02
Functional Analysis	Oct-02
Stakeholder Analysis	Oct-02
Home base testing of hardware	Dec-02
Needs Analysis	Dec-02
Cold climate testing	Feb-03
Value Hierarchy	Feb-03
Hot/Tropical climate testing	Mar-03
Vulnerability Assessment	Mar-03
Shock testing	Apr-03
Prototype Construction	Apr-03
Imagery Benefits Survey	Apr-03
Imagery Benefits Analysis	Apr-03
Final Outbriefing	May-03
Final Report Complete	May-03

1.4 Expected Profitability. This project will not generate any economic benefit to the government. However, the completed DAMTA with imagery enhancement will significantly improve user (unit and commander) understanding of current weather conditions and phenomena in battlefield areas they are preparing to occupy. Since the prototype DAMTA platform is being constructed by ATI under an SBIR contract, it has potential profitability implications for that company should they be selected to take it to Phase III (production).

1.5 Technical Results of the Project. The primary technical result of the project is the specific recommendation of off-the-shelf imagery sensors (cameras) that have withstood testing in cold, hot/tropical and temperate environments and are therefore deemed feasible for use on the DAMTA. All feasible cameras were compared to select the optimal alternative for this application based on both technical criteria and cost. Additionally, the study provides both drawings and a prototype demonstrating the mechanical details to integrate the selected cameras onto the current DAMTA prototype platform. Specifically, we have recommended a Micro Video MVC 3200 color pinhole camera as the optimal off-

the-shelf camera for this application. The MVC 3000 H color, high resolution, bullet camera is the research group's second choice.

Section 2 - Project Background

U.S. military operations depend heavily on current and accurate weather forecasts in the affected region. The Integrated Meteorological System (IMETS) is a software package that uses current weather forecasts to predict weather related affects on a multitude of Army, Air Force and Navy vehicles, aircraft and weapons platforms. It provides commanders in the field an opportunity to quickly discern how predicted weather will impact their ability to fight by assessing its affect on individual platforms. While the IMETS is a powerful and beneficial package, it is completely dependent upon accurate weather forecast data. Forecasts, in turn, are dependent upon the acquisition of current weather observations across the area of concern.

Current weather observations are often difficult or impossible to obtain when military operations are being conducted in a foreign, unfriendly nation. While high-level atmospheric conditions may be obtained, ground level phenomena are often missing complete information. Operations in Afghanistan are a prime example. U.S. Forces had almost no ground level weather data throughout the area of operations. Thus, forecasting tools were greatly limited and IMETS affects data were less accurate. These shortfalls in ground level weather data have prompted the development of a platform which can be air-dropped behind enemy lines to remotely collect and transmit standard weather observations across a large area back to friendly locations where the data can ingested by forecasting models.

In addition to standard weather observation data, the inclusion of imagery sensors on such a platform would provide additional weather information and potentially other tactical intelligence that would improve our understanding of battlefield weather and the tactical situation. Ground based imagery could provide information about blowing snow, sandstorms, sky conditions, ceiling, visibility, fog, smoke and haze. Additionally, it could provide real-time observation of unfriendly tactical vehicles or operations that may benefit friendly troops. While satellite imagery provides a good "over-the-top" view, ground based imagery provides an "under-the-weather" view yielding information that satellites cannot produce.

Real-time digital imagery would have been invaluable to commanders in Afghanistan, as it could have been their eyes on the battlefield. Continuously updated imagery and weather data could be a great combat multiplier for the United States Armed Forces, and the Disposable, Air-droppable, Meteorological Tower Array (DAMTA) has the ability to fill this void.

The DAMTA began as a means to provide the Army with the capability to gather meteorological data from battlefield areas that are data sparse. This data could then be used to enhance the accuracy of the Battlescale Forecast Model, as used in the IMETS. As the Army continues to improve its technology and move toward Force 21, IMETS will be used by tactical commanders at all levels of the Army. Commanders from echelons-above-corps, down to the company level, will be able to use this data to plan

operations. The goal of DAMTA is to enrich the IMETS to provide the most accurate and up to date weather data possible.

DAMTA will be a resource that can be deployed on any battlefield anywhere in the world. The DAMTA will consist of multiple individual meteorological towers, which will be dispersed over selected battlefield locations by an airborne platform. The towers will be capable of self-erecting to the vertical position after being dropped from a moving aircraft at no less than 2000 feet and at speeds up to 120 knots. Once deployed, these towers will communicate collected information to a central node (tower), which will in turn provide data to the IMETS and ultimately to the individual users. Figure 2.1 graphically depicts the five major functions of DAMTA.

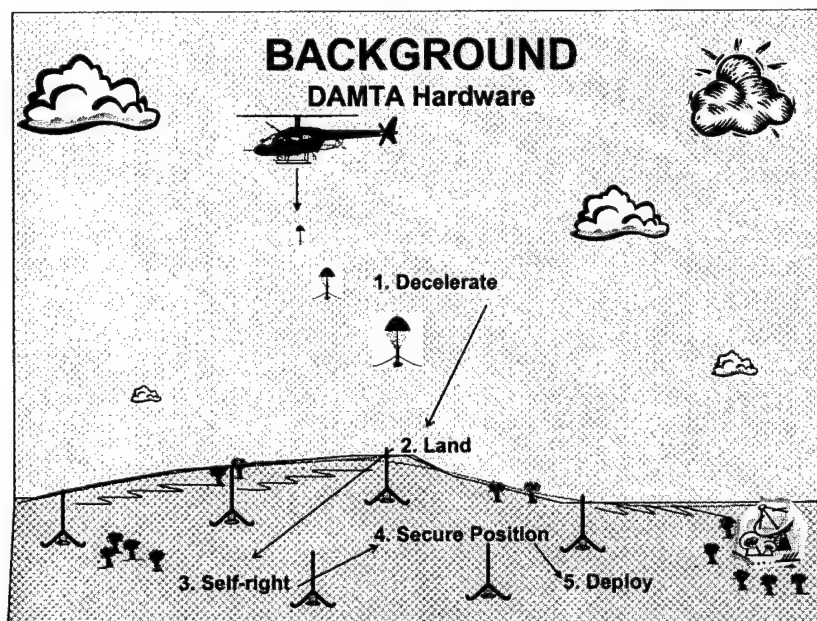


Figure 2.1 – Five functions of DAMTA platform

From January through May of 2002, a group of four U.S. Military Academy cadets worked in conjunction with LTC James Buckingham to conduct a preliminary design of the mechanical platform needed to safely transport the DAMTA from an aerial vehicle to the ground and initiate operation.

The group followed the Systems Engineering Design Process to develop and produce the effective need for the platform. The team then evaluated the necessary functions and developed approximately seven alternative designs to meet these functions. Using a Multi-Objective Decision Analysis, the team recommended the best alternative to the Army Research Laboratory (ARL) at a briefing in early April 2002. After the team and ARL agreed an alternative on, modeling of the selected alternative continued. This alternative incorporated a collapsible parachute, solid body construction, and spring-loaded legs as shown in Figure 2.2.



Figure 2.2 – Initial prototype DAMTA produced by USMA Research Team

The team constructed a basic prototype and presented it to ARL with the final findings of the project. This prototype was then passed on to ATI for design of the functional prototype. ATI produced it's initial prototype in November 2002 as shown in Figure 2.3. Their design is visually and functionally similar to the initial DAMTA design produced by the West Point research team.

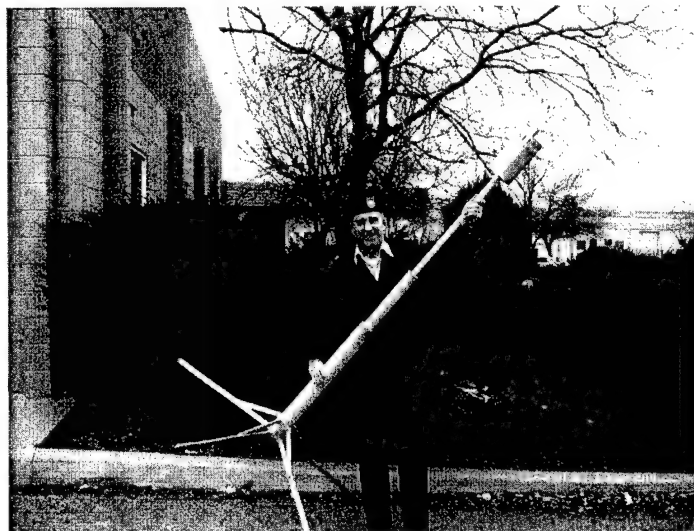


Figure 2.3 – Prototype of DAMTA platform produced by ATI

The preliminary function of DAMTA was the collection of weather data, but the scope of the project has broadened. LTC Buckingham and his team began to consider the potential benefits of digital imagery, and submitted a proposal to the University Partnering for Operational Support (UPOS) to research and recommend an alternative for the incorporation of imagery into the DAMTA platform. In the summer of 2002, LTC Buckingham was granted a \$100,000 contract for this endeavor. The DAMTA design encourages the use of off-the-shelf technology, so the imagery collection study was focused this direction. This imagery would provide valuable information not available through other sensors and yet highly desirable on the battlefield. This digital imagery would be integrated into the weather information that is being gathered and transmitted by the DAMTA. These pictures will provide commanders a more complete picture of the battlefield.

Over the summer of 2002, the team composition changed and work began focusing on the integration of imagery into the DAMTA platform. LTC Buckingham continued to serve as the driving force behind the project. MAJ Greg Lamm, Cadet Jacob Bailey, Cadet David Bunt, and Cadet Christopher Green joined the team. During the summer of 2002, Cadet Green spent three weeks at the White Sands Missile Range, New Mexico to begin research regarding potential off-the-shelf cameras to integrate into the platform. At the end of the three weeks, Cadet Green returned to USMA with specifications and proposals for ten potential cameras. These cameras were further studied and some were eventually purchased. The team took them and began extensive research and testing to create a proposal for the integration of digital imagery into the DAMTA platform. This report describes the project to enhance the DAMTA with imagery sensors as it was conducted over the period 21 August 2002 through 12 May 2003.

Section 3 – Project Mission and Deliverables

The mission and specific deliverables for this project are shown below. These have been gleaned from the initial UPOS proposal provided to the UPOS committee in February 2002.

3.1 Mission Statement. The mission of this project was to provide a recommendation for imagery enhancement to the DAMTA platform. This recommendation was to include an analysis of benefits that would accrue to the Army from the use of terrain-based, real-time imagery collection to enhance both weather and tactical intelligence gathering on the battlefield. In addition it was to include a specific recommendation of off-the-shelf imaging hardware and a physical prototype detailing how the selected camera would interface with the DAMTA platform. The ultimate purpose of the project is to augment and enhance the weather information provided by the DAMTA through the use of digital imagery sensors. A side benefit may be tactical intelligence provided by the imagery enhanced DAMTA when deployed behind enemy lines.

3.2 Deliverables. The original proposal cited three primary deliverables for this project as follows:

1. *Determine the benefits that digital imagery enhancement to the DAMTA brings to battlefield operations.* This is covered in Sections 5 and 6 in this report. Section 5, "Problem Definition", defines the problem and explains the methodology behind the research. Section 6, "Systems Integration" delineates benefits that accrue to the Army through imagery enhancement of the DAMTA.
2. *Research and recommend a viable, off-the-shelf, imagery sensor as an augmentation to the basic DAMTA platform capability.* This is covered in Section 7 entitled "Hardware Selection."
3. *Design and build a prototype that integrates the selected sensor with the current DAMTA platform design.* The design and production of the prototype is covered in section 8 entitled "Hardware Integration with DAMTA Platform."

Section 4 - General Approach (Project Organization)

4.1 Managerial Approach. The managerial approach for this project was somewhat unique since several organizations were involved in the project. The UPOS committee providing funding for the project in September 03. Dr. Ed Hume of the Johns Hopkins University Applied Physics Laboratory (JHUAPL) was the team's primary UPOS point of contact. Dr. Doug Brown from ARL-WSMR provided oversight as the primary interested agency. ATI, the Colorado based company that received the Phase II, SBIR contract to build the DAMTA prototypes provided information and feedback regarding the research team's efforts. The U.S. Military Academy research team from the Department of Systems Engineering conducted the research.

LTC Buckingham, the senior researcher, was the project manager and provided constant oversight for the project. MAJ Greg Lamm assisted LTC Buckingham by taking the lead role in the systems integration portion of the project. The three USMA cadets acted as assistant researchers and rotated responsibility as the lead engineer during the research period. This rotation provided the assistant researchers a chance to take ownership of the project and practice being a project manager, but also freed LTC Buckingham to do in depth research on the project without having to be encumbered by managerial tasks.

In addition to having a project manager, the group was organized into two main teams. The first team consisted of LTC Buckingham and CDT Christopher Green. Their main responsibility was to deal with the hardware and testing of the cameras as documented in sections 7 & 8. The second team consisted of MAJ Lamm and CDT David Bunt. Their primary responsibility was to work on the systems integration aspects of DAMTA and to determine the benefits that an imagery enhanced DAMTA would bring to the battlefield. This is documented in sections 5 & 6. Their work included a survey of active duty army officers to help determine the benefits that would accrue to users through the use of imagery. They also maintained the design team web page and worked to track the budget for the project. The group's fifth member, CDT Bailey, was the group secretary and provided primary assistance in project documentation.

A basic internal linear responsibility chart that was used for the USMA research team is shown as Table 4.1.

Table 4.1 – Linear Responsibility Chart

Task	Responsibility				
	LTC Buckingham	MAJ Lamm	CDT Bailey	CDT Bunt	CDT Green
Project Manager	R	S	S	S	S
Lead Engineer	S	S	R	R	R
Purchasing Equipment	R	S	S	S	R
Website	S	R	S	R	S
Budget	S	R	S	R	S
Research	S	R	S	R	S
Maintain Journal			R	R	R
Monthly Reports	S	S	R	S	S
IPRs	S	S	R	R	R
Final Report	A,S	A,S	R	R	R
Final Presentation	A,S	A,S	R	R	R

R Responsible
 S Supporting
 N Notification
 A Approval

LTC Buckingham held meetings approximately once a week to review progress, present new information, establish deadlines and keep the group on track. In addition LTC Buckingham and MAJ Lamm met independently with Cadets Green and Bunt respectively to work specific research issues on the project.

4.2 Technical Approach. The imagery enhanced DAMTA project is a derivative project. The technology that we were working with was already in place, as was the design for the DAMTA platform. The team's focus was to enhance the current platform using imagery devices.

The technical requirements for the project were achieved by creating and adhering to a sound project schedule. Microsoft Project 2002® was used to create a project action plan composed of all the anticipated project tasks. Task durations were established, milestones were set, and the schedule was disciplined to ensure required deadlines were met. Each design team (systems integration and hardware) had their own set of tasks but everyone was encouraged to work together and share ideas to make the project better.

The team had expertise in Mechanical Engineering, Engineering Management and Civil Engineering. This expertise was focused to assist with technical issues that arose during the project. In addition, the team tapped expertise in Computer Aided Drawing (CAD) through another faculty member

and used that to assist with prototype design and construction. In addition, LTC Buckingham had previous experience with constructing and deploying remote imaging systems, which was fed directly into this project.

4.3 Supporting Organizations. Several supporting organizations were involved in the project. They are listed and explained in Table 4.2.

Table 4.2 – Supporting Organizations

Organization	Location	Charter
University Partnering for Operational Support (UPOS)	Johns Hopkins University (Administers Program)	Accepts proposals and provides funding and oversight for proposals that support DOD needs
Army Research Labs – White Sands Missile Range, NM (ARL-WSMR)	White Sands Missile Range, NM	Strong project supporter. Contracted with ATI to provide Phase II, SBIR for DAMTA project.
Cold Regions Test Center (CRTC)	Fort Greely, AK	Provided support for cold weather testing
Yuma Proving Grounds (YPG)	Yuma, AZ	Provided support for hot/tropical testing in Gamboa, Panama
Department of Civil and Mechanical Engineering (CME)	West Point, NY	Provided expertise in CAD and initial prototype development
Director of Information Management (DOIM)	West Point, NY	Assisted with final prototype construction
Applied Technologies Incorporated	Longmont, CO	Contracted to provide prototype DAMTA platforms to ARL-WSMR as part of Phase II, SBIR project

4.4 Contractual Aspects. The team did not initiate any contracts with civilian agencies during the course of the project. Payments were made to two military organizations to support camera testing. CRTC in Fort Greely, Alaska was paid \$4,500 to support cold weather testing in their cold chamber and at their outdoor test site a Bolio Lake. YPG in Yuma, Arizona was paid \$2,000 to support hot/tropical weather testing at their site in Gamboa, Panama.

Our team had an agreement with UPOS by virtue of the proposal we submitted to do the research on integration of imagery sensors with the DAMTA. UPOS provided us with \$100K to conduct this research. The funds covered hardware purchases, hardware testing, travel, and research conducted during the study. The research team has met the deliverables delineated in the proposal as documented in this report.

4.5 Schedule. The Microsoft Project file used to oversee and control this project is attached at Appendix A. This GANTT chart establishes the primary task list for the project to include each tasks anticipated duration, percentage completion and start/stop dates. This chart was used to help control the project.

4.6 Resource Requirements. The project proposal included an estimated budget of \$100K. The expenses were broken down into five major categories. These five categories included departmental expenses, consulting/contractual, travel, equipment purchases, and miscellaneous costs. A snapshot of the projected expenses versus our current status is shown in the table below:

Table 4.3 – Budget Categories

Type	Budget	Actual	Remaining
Departmental	\$27,000.00	\$20,774.77	\$6,225.23
Travel	\$8,000.00	\$4,504.31	\$3,495.69
Consulting/Contractual	\$33,200.00	\$7,064.15	\$26,135.85
Equipment	\$29,200.00	\$4,260.47	\$24,939.53
Other/Misc.	\$2,900.00	\$0.00	\$2,900.00
Total	\$100,300.00	\$36,603.70	\$63,696.30

It is important to note several things. First, departmental expenses are those that go to the Department of Systems Engineering at their discretion. Additionally, they spent \$2,660.00 on DAMTA, which is not included in these figures.

The budget was tracked in an Excel spreadsheet. This is how we decided to monitor the cost, and it allowed us to easily access and track expenses. The materials that were required for the completion of this project included extra equipment, more cameras, travel to conferences and test locations, contractual aspects with testing companies, as well as miscellaneous expenses. Our procedure for controlling cost was to frequently monitor the expenses in our Excel sheet and to attempt to stay within the budgeted costs for each category, however if we felt that we would not use all of the funds in a particular category, then we transferred funds to the other category. For an electronic copy of the Excel sheet budget, please contact CDT David Bunt, x34021@usma.edu.

4.7 Personnel. The team for this project consisted of five members; two of who are USMA faculty and three are USMA cadets. The senior investigator for this project was LTC James M. Buckingham, P.E., Ph.D. and the deputy was MAJ Greg Lamm. The three cadet members are CDT Christopher Green, CDT David Bunt, and CDT Jacob Bailey. LTC Buckingham began doing work related to the DAMTA during his doctoral work at University of Alaska Fairbanks and has used this knowledge to be the driving force behind the DAMTA project. He has a BS and MS in Mechanical Engineering and a Ph.D. in Engineering Management. MAJ Lamm has a MS in systems engineering that provided experience for his work with

the systems integration portion of the project. Both LTC Buckingham and MAJ Lamm used this knowledge to mentor and direct the three cadet members of the team throughout the semester. Cadet Green is an engineering management major with a mechanical engineering sequence. His engineering management skills were useful in supervising the project and his mechanical engineering skills were useful for the hardware work. Cadets Bailey and Bunt are both engineering management majors that also possess the necessary skills to oversee the project team as well as function as members of the team.

The members of the team needed ProDesktop© software to design and build prototypes of the modular structure that was used to analyze the best way to integrate imagery collection devices with the DAMTA platform. All members of the team were also responsible for learning how to work with the cameras in order to test and analyze them. Also, each member spent a semester working with and becoming proficient in MS Project©. There were no legal requirements or security clearances needed beyond what the cadets and officers already had.

4.8 Facility Support. The project team had a room at USMA devoted solely to the DAMTA project. This room was used to store all materials and cameras and served as a workshop to construct and test cameras. Facilities under CRTC and YPG control were used for cold and hot/tropical weather testing respectively. The impact of these facilities on the project is discussed more specifically in Section 7.2.3.

4.9 Issues Resolved. There were two problematic issues that had to be resolved during the project. Each is discussed below.

YPG Support to Hot/Tropical Weather Test – Initial coordination in November 2002 indicated their hot/tropical test site in Panama would support our needs. A test plan was written and forwarded to YPG in February 2003. One week prior to the test, we were informed that the test site at Fort Sherman, Panama had no electrical power and not telephone lines, both of which were critical to the test. The site was moved to an alternate location in Gamboa, Panama, which had electric power but no telephone. This shortfall meant that we could not remotely monitor cameras during the hot/tropical test from the home base location at West Point, NY. While the test was still conducted on site in Panama, it was substantially shorter than planned. This is discussed in detail in Section 7.2.3.3.

Impact of Research on ATI – Phase II of the SBIR project obligated ATI to provide prototype towers within 24 months of the contract start date. These towers need only provide the basic weather information: wind speed, wind direction, humidity, barometric pressure and temperature. Therefore ATIs primary focus during our research was not on imagery enhancement to the DAMTA. LTC Buckingham met with ATI in December 2002 at their location in Longmont, CO. The meeting concluded with an understanding that while the USMA research had merit and benefit, ATI would not focus on imagery

enhancement until their primary work on the DAMTA prototype was complete. Additionally, some member of the ATI team felt that a custom imagery solution (rather than an off-the-shelf solution) would eventually be best as it would allow components to be optimized with the whole system. The USMA team maintained contact with ATI throughout the research, but recognized that portions of their contributions would be dated by the time ATI was prepared to focus squarely on imagery enhancement. This did not deter the team from pursuing their obligation in the proposal to research and recommend the best off-the-shelf imagery sensor for the application. Ultimately, the USMA team provided a recommendation for physical camera integration with the DAMTA that would benefit ATI whether or not the cameras themselves were custom made and optimized to the platform's electronic requirements.

Section 5. Problem Definition

5.1 Needs Analysis. In order to begin the needs analysis of our system, we had to conduct a system decomposition. We first identified the super-system, in other words, the parent system to the DAMTA platform. The DAMTA platform functions as an individual unit in a series of platforms that transmit data back to a single node. From this node, ground commanders can gain intelligence and access to the information on battlefields. This system of linking individual platforms to a node and transmitting weather and imagery data to commanders is the super-system to the DAMTA platform. From that, we could begin to visualize how each individual DAMTA platform would fit into the super-system.

The lateral systems that exist for the purposes of this project are the other platforms that are being linked together. They work together to gather weather and imagery information across the battlefield and transmit it back to the central node. It is the sum of all of these lateral systems that makes the DAMTA intelligence so critical; it provides a wealth of information across a multitude of platforms, thus maximizing battlefield awareness.

Finally, we considered what subsystems existed within the DAMTA platform to make the system complete. The DAMTA platform is composed of many subsystems. These subsystems include the parachute, the landing apparatus, the self-righting mechanism, the weather collection equipment, the imagery equipment, and the capability to send the information back to the central node for dispersion to ground commanders.

5.2 Stakeholder Analysis and why is weather so important? U.S. operations in Afghanistan and Iraq taught the United States Armed Forces many lessons. The importance of seeing the battlefield before operating in a specific region is one. Although U.S. forces possess many tools and technologies to develop models for terrain and weather data (i.e., satellite imagery, forward observers and simulated sketches), they still have very little knowledge or situational awareness of key aspects of the battlefield at a precise moment. Situational awareness is formally defined as *the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future* and has three levels: perception, comprehension, and projection [Endsely, 1995]. Digital imagery provides a means to verify and improve an individual's perception of weather and its affects on specific missions. It is essential to focus on an individual's perception because comprehension and projection are based on that original perception. DAMTA provides the capability to bridge the gap between perception and reality thus increasing battlefield situational awareness.

For example, in Afghanistan, satellite imagery did not provide much information about visibility on the ground or precise weather data. This caused concern among military commanders as they were

preparing operations in the desert. Figure 5.1 illustrates the importance of weather analysis in the Intelligence Preparation on the Battlefield (IPB) and tactical decision-making processes because it accounts for 25% of the uncertainty in operational analysis. Weather affects all domains of military operations including chemical and biological effects prevention, weapon ranges, ground reconnaissance, air assault and airborne operations, airlift, night, psychological, and logistic operations [Field Manual 34-81, Chap 4, 1989] and [Field Manual 34-81-1 (1992), Appendix]. Weather has such a great impact on operations that it can cause an air assault mission to become extremely dangerous (high risk). Each branch of the Army from aviators to logisticians requires some weather data to predict, plan and prepare for military operations. FM 34-81-1 (1992), Chapter 3 (Battlefield Weather Effects) depicts the requirements needed for specific military operations including weather-reporting frequency; the weather effects on battlefield applications (e.g., artillery fires, concealment, radar) and the criteria for changing operations based on weather.

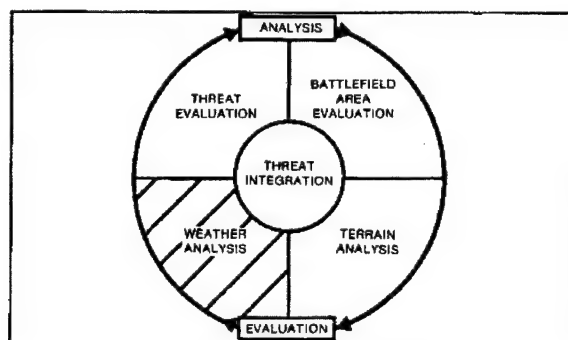


Figure 4-1. IPB process.

Figure 5.1 - Weather Analysis on the Battlefield [Field Manual 34-81 (Weather Support for Army Tactical Operations), 1989]

The systems integration problem statement is to determine the benefits that digital imagery enhancement to the DAMTA will bring to battlefield operations. The military needs to gather accurate and timely weather data within all operations and training environments. Weather imagery improves the accuracy and timeliness of critical data needed to prepare, plan, and execute operations. Stakeholder analysis is a key engineering tool that involves: 1) identifying the stakeholders, 2) developing the means to gather data from the stakeholders (i.e., interviews, surveys), 3) conducting interviews, surveys, etc. and 4) displaying the affinity diagram (organized depiction of the key objectives and concerns of the stakeholders). An affinity diagram is illustrated in Section 6 (Systems Integration) as a culmination of the stakeholder survey, which was conducted, to assist with the research. Stakeholders are any individual or group that influences or has an interest in a problem. Our client (chief decision-maker) is University Partnership for Operational Support (UPOS), who gave us the grant to conduct research on the imagery integration of the DAMTA platform. Other key stakeholders that influence the problem include: future

users of the DAMTA technology, other research organizations, research analyst from West Point, and other Army organizations that benefit from the research and its applications. We consider the Army to be a critical stakeholder, not just because they are the users, but also because they benefit from the research. The Army gains a great deal from having its own members conduct research and implement new technology.

Our primary focus was to aid ground commanders, however we remain optimistic that some, if not all, of these other communities could benefit from implementing DAMTA technology. On a broader sense, the DAMTA platform has the potential to change the way the Army plans for and fights in battle. The DAMTA platform possesses the ability to benefit other communities (Table 5.1). For example, firefighters could use DAMTA as a means to gather data and images of forest fires and monitor changing weather conditions for remote areas. This information increases the ability to fight the fire more efficiently with a reduced risk.

Table 5.1 - Stakeholder Table

Stakeholders	Possible Uses
Tactical Commanders and Staffs	• Verify and Enhance Conventional Weather Information
	• Collect, interpret and disseminate current weather observations
	• Collect, interpret and disseminate tactical intelligence
	• Improve accuracy of weather forecasts
Army Research Laboratory (ARL)	• Future research
	• Meet Army requirements
Civilian Aviators	• Manage flight hours
	• Save resources
	• Interpret image ceiling data
Emergency Disaster Recovery Cells	• Manage severe weather situations
	• Provide real time digital images to users
	• Forecast weather and provide analysis
Environmental Protection Agency (EPA)	• Use digital images to collect, interpret local weather and its impacts on hazard areas
Federal Aviation Administration (FAA)	• Redundant weather collector; backup for primary systems
	• Monitor severe weather situations
Firefighters	• Gather data and images of forest fires and monitor changing weather conditions for remote areas.
Forestry Departments	• Monitor severe weather situations
	• Provide information to visiting personnel
	• Monitor remote areas
Geologists	• Monitor local weather and analyze its impacts

Mayor/Governors	• Mange severe weather situations
	• Provide information to emergency personnel and citizens
	• Prepare, plan and execute emergency operations.
Meteorologists	• Redundant weather collector; backup for primary systems
	• Verify local weather situation
Military Weather Cells	• Redundant weather collector; backup for primary systems
	• Verify weather in remote areas where ground weather data is important
National Aeronautical Space Agency	• Redundant weather collector; backup for primary systems
	• Verify local weather situation
	• Forecast weather and provide analysis
National Park Service	• Monitor severe weather situations
	• Provide information to visiting personnel
	• Monitor remote areas
National Weather Service	• Monitor severe weather situations
	• Verify local weather situation
	• Monitor remote areas
	• Redundant weather collector; backup for primary systems
	• Forecast weather and provide analysis
Oil Exploration Firms	• Assist in monitoring, tracking and predicting weather patterns. Provide weather data to users as a means to prepare, plan and execute missions.
Recreational Businesses	
Seismologists	
Volcanologists	

5.3 Functional Analysis. Functional analysis helps one to understand the requirement surrounding the system; the complexity and issues involved with the entire DAMTA system and its integration into the current weather system. The resulting functional representation yields four main functions with sub-functions. Figure 5.2 illustrates the functional hierarchy for the DAMTA platform. The survey will help us *expand* and *define* additional functions. Some functions in Table 5.2 were gathered from the DAMTA survey. One function not depicted in the diagram is "Saving Resources." Many of our survey results link accurate weather data (i.e., image) to saving battlefield resources. For example, if one could know the current or even future weather (6 hours from now), you may cancel projected missions that will save lives, protect equipment and control momentum on the battlefield. On the other hand you may choose not to cancel the mission so you do not miss an opportunity to gain momentum. The functions that digital imagery may provide allow commanders and staffs to accurately weigh the risks of an operation or a series of operations.

Table 5.2 defines the four main functions of the functional hierarchy. Only the “Collect, Interpret and Disseminate Tactical Intelligence” function represents a by-product that is formed from the DAMTA platform because DAMTA’s primary mission is to collect weather information. Functional analysis is the basis for values of the systems (what stakeholders feel is important about the system) and the end state goal of the system (what the system must do). Table 5.3 defines each of the sub-functions below the four main functions. We attempt to develop a system that executes each of these functions. Components are built or procured to fit each of the functions based on the scope of the problem.

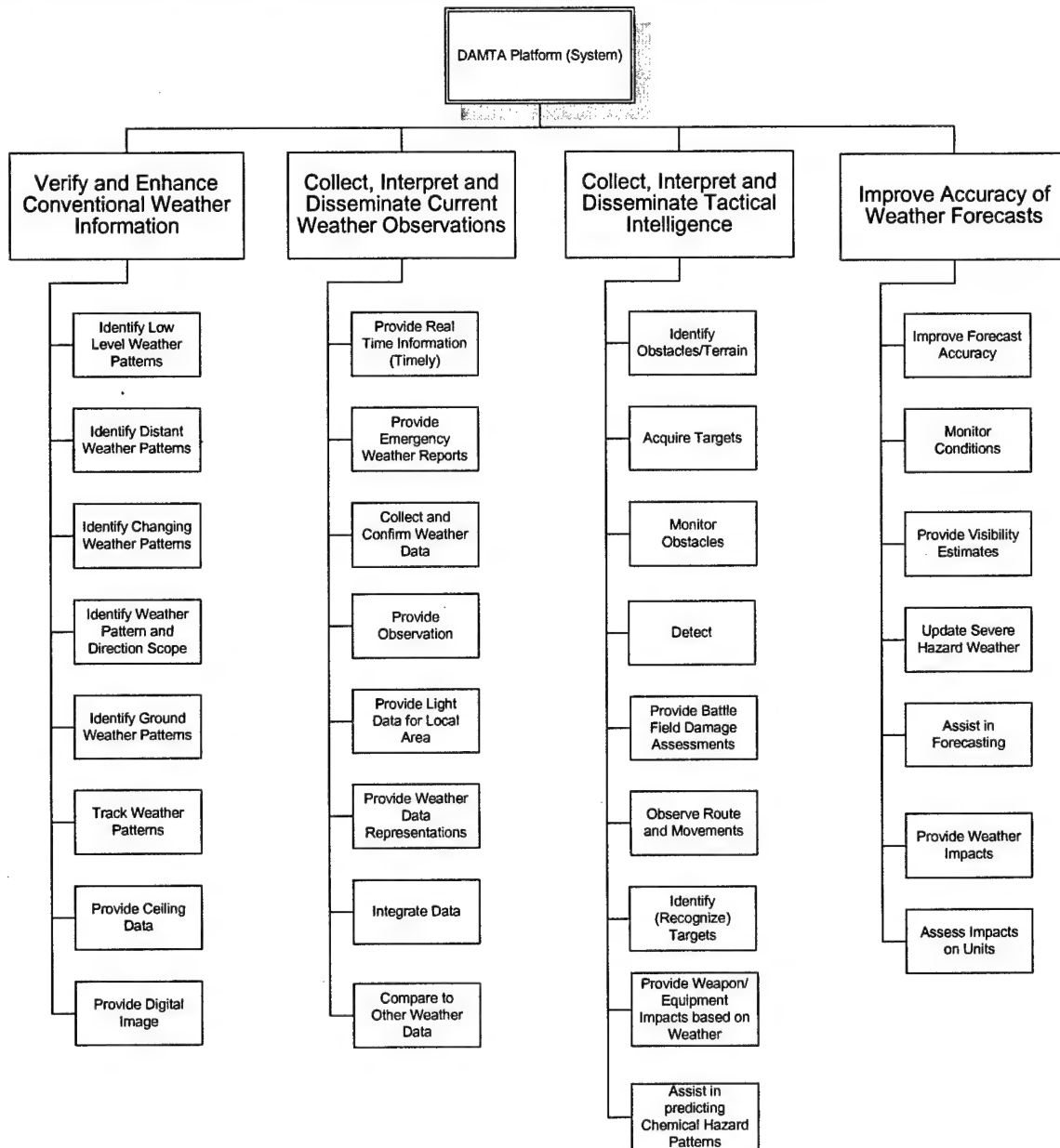


Figure 5.2 - DAMTA Functional Hierarchy

Table 5.2 - Functional Definition Table

Functions	Definitions
Verify and Enhance Conventional Weather Information	Confirm the truth of, and increase situational awareness through weather data.
Collect, Interpret and Disseminate Current Weather Observations	Obtain raw weather data from remote areas, process (perform analysis on) the weather data and transfer the knowledge to the lowest level.
Collect, Interpret and Disseminate Tactical Intelligence	Obtain raw tactical data from remote areas, process (perform analysis on) the tactical data and transfer the knowledge to the lowest level.
Improve Accuracy of Weather Forecasts	Increase the quality and value of weather prediction.

Table 5.3 - Sub-function Definition Table

Functions	Sub-Functions	Focus
Verify and Enhance Conventional Weather Information	Identify Distant Weather Patterns	Focus on incoming and outgoing weather conditions
	Identify Changing Weather Patterns	Focus on the various weather scenarios and their timeline
	Identify Low Level Weather Patterns	Focus on ceiling and below weather situations
	Identify Weather Pattern and Direction Scope	Focus on current weather situations and the direction of movement
	Identify Ground Weather Patterns	Focus on weather scenarios forming around the DAMTA platform (e.g., dust storms, floods)
	Track Weather Patterns	Focus on monitoring and verifying weather data
	Provide Ceiling Data	Focus on aviation data needed for planes and helicopters. Focus on impact of light on night operations.
	Provide Digital Image	Focus on near real-time pictures to users
Collect, Interpret and Disseminate Current Weather Observations	Provide Emergency Weather Reports	Focus on disseminating abrupt weather changes
	Collect and Confirm Weather Data	Compare digital images to other weather data
	Provide Real Time Information (Timely)	Disseminate information to ground commanders and staffs
	Provide Observation	Observe weather impacts and interpret data
	Provide Light Data for Local Area	Compare and interpret digital imagery light data and its impact on users
	Provide Weather Data Representations	Provide an accurate model of the current weather and gain key insight into the digital image.
	Integrate Data	Combine all weather resources to better interpret and verify weather scenarios
	Compare to Other Weather Data	Compare to other weather resources (e.g., balloon, satellite)

Functions (Continued)	Sub-Functions	Focus
Collect, Interpret and Disseminate Tactical Intelligence	Identify Obstacles/Terrain	Focus on gaining tactical advantage on the battlefield by increasing situational awareness and intelligence while minimizing risks to soldiers and operations
	Acquire Targets	
	Monitor Obstacles	
	Detect	
	Provide Battle Field Damage Assessments	
	Observe Route and Movements	
	Identify (Recognize) Targets	
	Provide Weapon/Equipment Impacts based on Weather	
Improve Accuracy of Weather Forecasts	Improve Forecast Accuracy	Allows staff to better predict the impacts of future weather scenarios on units and monitor those conditions over time
	Monitor Conditions	
	Provide Visibility Estimates	
	Update Severe Hazard Weather	
	Provide Weather Impacts	
	Assist in Forecasting	
	Assess Impacts on Units	

5.4 Value System Modeling. Value system modeling allows analysts to organize functions (what the system must do), objectives (level of attaining those functions), and evaluation measures (how to measure the success of new alternatives and the current system). A value system represents the relationships and trade-offs of objectives of the system defined by the stakeholders. A value hierarchy is a method to arrange the value system model in order to: 1) quantitatively measure the importance of objectives, 2) guide information collection, 3) identify alternatives, 4) identify relationships and tradeoffs, and 5) evaluate alternatives [Kirkwood, 1997]. Initially based on literary research and interviews we developed a relationship table and a trade-off table, which culminated into a final value hierarchy as shown in Figure 5.3. The system integration value hierarchy will be used to configure the imagery device with the DAMTA platform. A separate hardware value hierarchy will be used to perform multi-objective decision analysis on which imagery device should be recommended for the DAMTA platform. Based on the initial problem statement, client input and time available, specific objectives were deleted from the value hierarchy (highlighted with a red box and a black X). The adjusted value hierarchy helped guide the hardware research and will also assist in future DAMTA research projects.

Two important points about value hierarchies and value modeling: 1) the structuring of the hierarchy is important (top-down or bottom-up) and 2) the objectives should represent the final purpose (ends) of the problem (project) not the means [Kirkwood, 1997]. If alternatives are known, then a bottom-up approach is appropriate. In this approach you select the evaluation measures prior to the objectives and functions. Although we have a general idea of what the DAMTA platform looks like, we do not have an alternative for how the imagery should be configured. Based on this lack of alternative knowledge, a top-down approach was used. The use of the surveys and brainstorming assisted in identifying the ends and not the means.

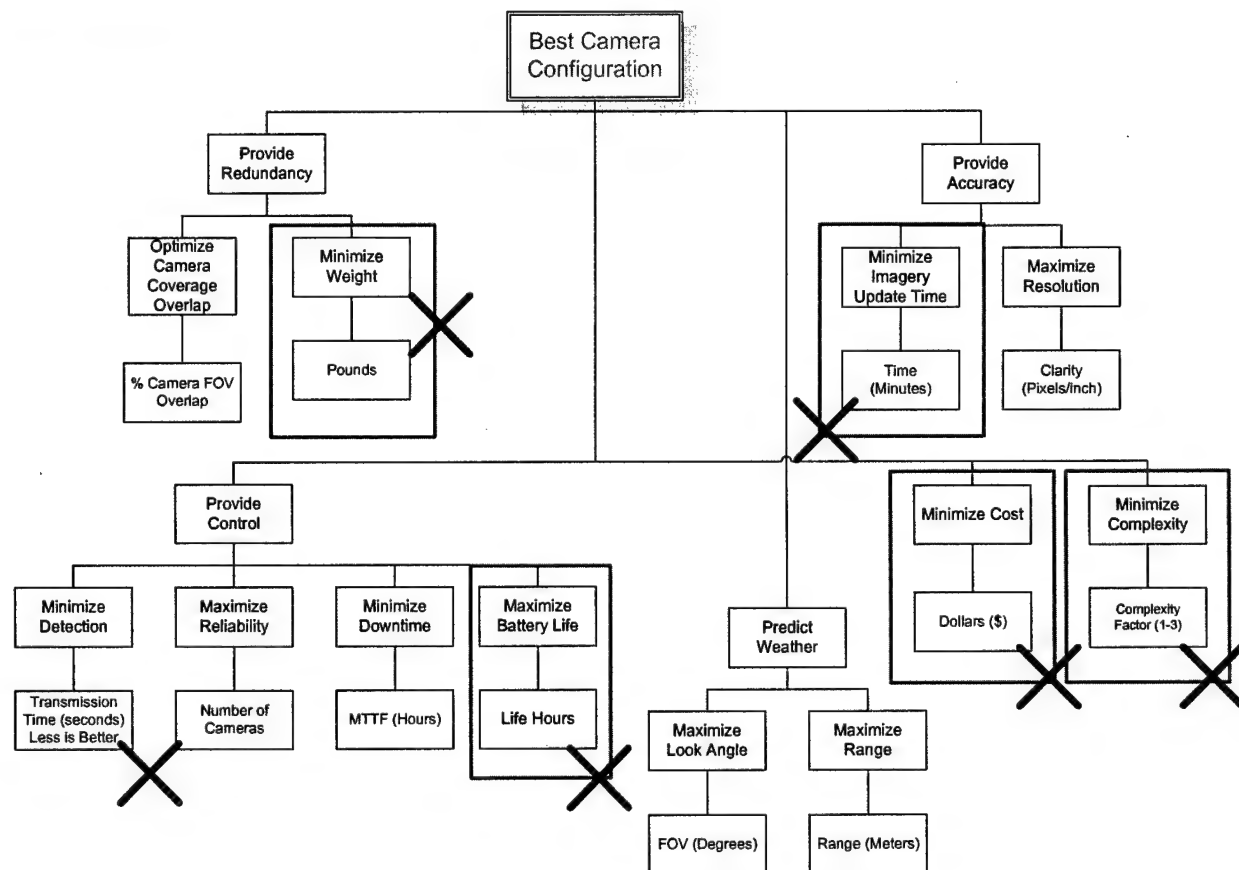


Figure 5.3 - DAMTA Value Hierarchy

It is important to identify the key relationships and tradeoff between attributes in this multi-dimensional problem (Tables 5.4 and 5.5, respectively). The relationship table defines the major attributes and the dependence between attributes. For example, as redundancy is increased (adding more cameras, processors, or camera management schemes) within the DAMTA platform so is the control of the camera and the quality of digital imagery that is sent to the users. The tradeoff table identifies the major tradeoffs and dependence between attributes. The designs of these attributes play a critical role in the overall

performance of the system. Through design and project management ingenious components and policies may allow both attributes to boost the overall system performance. Future work will be to identify the points of diminishing return of the tradeoff attributes and validate theoretical values to the actual tradeoff values through modeling and simulation. Tradeoff testing requirements were developed for Networked Unattended Ground Sensors by Lamm, L. et al.

Table 5.4 - DAMTA Attribute Relationships

Redundancy	vs.	Control
Control (tilt)	vs.	Bandwidth
Field of View (FOV)	vs.	Reliability
Accuracy	vs.	Correction
Accuracy	vs.	Control
Distance (Range)	vs.	Accuracy
Overlap (FOV)	vs.	Redundancy
Cost	vs.	Redundancy
Complexity Factor	vs.	Reliability
Number of Cameras	vs.	Field of View
Coverage	vs.	Range/Number of Cameras
Update Time	vs.	Battery Life
Reliability	vs.	Control

Table 5.5 - DAMTA Attribute Tradeoffs

Weight (descent)	vs.	Redundancy
Field of View	vs.	Resolution
Risk	vs.	Redundancy
Control	vs.	Mean Time to Failure (MTTF)
Control	vs.	Detection
Imagery Update Time	vs.	Detection (Bandwidth)

The compilation of all of this work and knowledge made it possible to develop our Engineering Problem Statement: 1) Determine the benefits that digital imagery enhancement to the DAMTA brings to battlefield operations, 2) Research and recommend a viable, off-the-shelf, imagery sensor as an augmentation to the basic DAMTA platform capability, and 3) Design and build a prototype that integrates the selected sensor with the current DAMTA platform design.

Section 6 – Systems Integration

A team of five engineers conducted this engineering research project utilizing several engineering management techniques to plan, execute, analyze and control the research. The research techniques included economic analysis, multi-objective decision analysis, project management, and a problem solving methodology (i.e., Systems Engineering and Management Process (SEMP) developed at the United States Military Academy, Systems Engineering Department) as a template for conducting the study.

The five-person team was segregated into two teams: a hardware team and a systems integration team. Both teams developed a long-range project management schedule of events and investigated the feasibility of augmenting the basic DAMTA sensor array with imagery collection sensors. The two teams overall goal was to improve the accuracy of meteorological forecasts in support of: 1) long-range weapons, 2) biological and chemical weapon hazards, 3) aviation needs, 4) ground maneuver assets and 5) civilian applications. Table 6.1 highlights each of the teams' tasks and the specific tools the systems integration team used in this study.

The following chapter is a summation of the survey conducted by the DAMTA systems integration team. The systems integration problem statement: *To determine the benefits that digital imagery enhancement to the DAMTA brings to battlefield operations.* We understand that the military needs to gather accurate and timely weather data within all operations and training environments. The imagery benefits survey showed that weather imagery improves the accuracy and timeliness of critical data needed to prepare, plan, and execute operations.

Table 6.1 - DAMTA Project Management Scheme

Hardware Team	Systems Integration Team	System Engineering Analysis Tools
Develop a project management schedule of events.		Project Management
Explain current research into imagery sensors being considered as an enhancement to the basic functions of the DAMTA platform.	Explore how imagery assists specific military communities and other disciplines.	Stakeholder Analysis (includes survey)
	Explore DAMTA's imagery capabilities, and their application and integration in future military operations.	Functional Analysis
Provide recommendations for off-the-shelf hardware to that enhances DAMTA's platform capabilities.	Analyze the benefits of imagery by researching the trade-offs, attributes, relationships and values that users place on the configuration of imagery-capturing devices.	Value System Modeling (includes survey)
	Evaluate the vulnerabilities of imagery-based components on sensors in specific environments.	Vulnerability and Risk Analysis

6.1 Imagery Benefits. The benefits of the DAMTA platform have been captured in survey responses obtained from personnel at USMA. In Chapter 5.2, we examined several other communities that could benefit from the DAMTA platform and their possible applications (See Table 5.2). A list of the survey questions and web results are located in the following section (Section 6.2).

In previous research, a division of ARL, Night Vision and Electronic Sensor Directorate (NVESD), conducted a Smart Sensor Web Experiment to assess the impact of four chosen sensor concepts on the situation awareness of individual combatants in a Military Operations in Urban Terrain (MOUT) in November 2002. The four concepts (alternatives) were:

- Alternative 1: Distributed cueing sensors with no imagery sensors.
- Alternative 2: Hovering and perching Unattended Aerial Vehicles (UAV) plus distributed cueing sensors with no imagery sensors.
- Alternative 3: Distributed cueing sensors with no imagery sensors with fixed imagers and hovering and perching UAVs.
- Alternative 4: Advanced sensors including Unattended Ground Sensors (UGS) with slewing imagers and hovering and perching UAVs [CECOM, 2002].

NVESD conducted extensive simulations to evaluate each alternative using the critical evaluation measure of situational awareness. Each alternative presented specific observations including validation methods, discriminating information, cost to the commander (e.g., resources, effort and time), level of certainty, commander and staff evaluation methods and overall situational awareness information capabilities and levels. The conclusion of the NVESD study found that:

- Accurate and complete situation awareness data has the most influence on the battlefield.
- The more accurate the information, the more effective the unit.
- Video was not essential to the individual soldier and was too time and bandwidth intensive. It may be impractical over wireless LAN because it requires a lot of bandwidth. In some cases 100 times the bandwidth compared to simple 1's and 0's.

6.1.1 Imagery Benefits Online Survey and Results. Based on the comments contained in the Smart Sensor Web Experiment, previous 2001-2002 DAMTA research conducted by USMA cadets, and literary research ([Field Manual 34-81 Chapters 3 & 4, 1989], [Field Manual 34-81-1, 1992], [Buckingham, 2000] and [Lamm, L et al., 2002]) a 17-question survey was constructed to explore the values placed on imagery by potential users and investigate the benefits an imagery device can offer in specific environments. Initially several surveys were constructed for the military communities (e.g., aviation, intelligence, maneuver and meteorology communities), and government agencies (e.g., Federal Aviation Administration, National Forest Service and Environmental Protection Agency). After careful examination, it was decided to focus our efforts on the military communities. The on-line survey is located at: <http://www.se.usma.edu/DAMTA/survey.asp> and the survey results are located at http://www.se.usma.edu/DAMTA/Survey_results.asp.

The survey was sent to 592 military personnel at the United States Military Academy (USMA) and remained active for a two-week period (4-21 April 2003). The survey was completed on 21 April with 200 respondents. USMA represents a very good population correlating to the Active Army (Tables 6.2 and 6.3). The USMA population has personnel that have seen combat, used potential future combat systems, conducted research in areas relating to DAMTA and have valuable knowledge about the future requirements of imagery on the battlefield. We have requested current Army demographics from Department of the Army in order to verify the correlation between USMA and the U.S. Army. Warrant Officers (4) were tallied with the Aviation branch and Special Forces Officers (9) were tallied with the Infantry Branch.

Table 6.2 - DAMTA Survey Demographics (U.S. Army Branch)

Branch	Before Survey Count	Number Responding	Percent (%) Responding for a Single Branch	Respondents Percentage based on Branch (%) {based on the 200}
ADA	24	8	33.3%	4.00%
Armor	52	19	36.5%	9.50%
Aviation	63	28	44.4%	14.00%
Chemical	15	8	53.3%	4.00%
Engineers	83	24	28.9%	12.00%
Field Artillery	83	29	34.9%	14.50%
Infantry	103	37	35.9%	18.50%
Military Intelligence	39	15	38.5%	7.50%
Military Police	28	7	25.0%	3.50%
Ordinance	24	8	33.3%	4.00%
Quartermaster	11	3	27.3%	1.50%
Signal	39	11	28.2%	5.50%
Transportation	13	3	23.1%	1.50%

Table 6.3 - DAMTA Survey Demographics (Rank/Grade)

Rank	Before Survey Count	Number Responding	Percent (%) Responding for a Single Rank	Respondents Percentage based on Rank (%) {based on the 200}
COL	52	8	15.4%	4.00%
LTC	122	48	39.3%	24.00%
CPT	191	50	26.2%	25.00%
MAJ	217	90	41.5%	45.00%
Chief Warrants	7	4	57.1%	2.00%

The following tables (Tables 6.4 to 6.10) show each question from the survey and a snapshot of the results. Section 6.3 provides in depth analysis for each question. Results are initially presented as averages or percentages of respondents that selected that particular choice.

Table 6.4 - DAMTA Survey Question 1 and Results

<i>Question</i>	<i>Possible Choices</i>	<i>Results</i>
1. Which tactical weather information sources have you used in the past either in training or real-world army missions? (Check all that apply)	Human Assets (Scout, etc.)	67.50%
	Intelligence Assets	66.50%
	Satellite	50.00%
	Intra-/Inter-net	40.00%
	Aviation Assets	34.50%

	Sensors	23.50%
	Unmanned Aerial Vehicle (UAV)	13.50%
	Robotics (Unmanned Ground Vehicle (UGV))	1.50%
	Other: Fill-in	Figure 6.1

Figure 6.1 represents a consolidation of other tactical weather information resources that personnel have used in the past. Most of the Field Artillery Officers have used either a balloon system or received weather data from the Air Force.

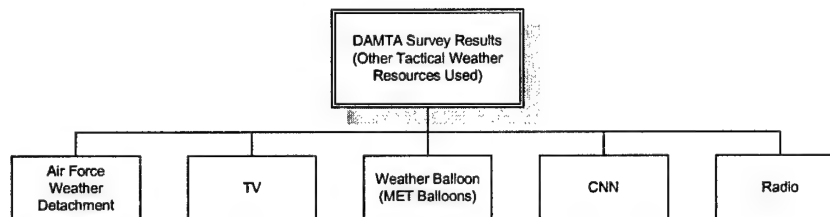


Figure 6.1 - Question 1 Open Responses Summary Diagram

Table 6.5 - DAMTA Survey Question 2 and Results

Question	Possible Choices		Results
2. Select the two most important pieces of weather information based on the benefits it would provide you as a tactical leader. Please fill-in any other weather information that is important to you.	Most important:	Visibility	45.00%
		Precipitation	18.50%
		Temperature	12.50%
		Wind Speed	10.50%
		Wind Direction	9.00%
		Sky Conditions	3.50%
		Dew Point	1.00%
	Next most important:	Precipitation	23.50%
		Temperature	22.00%
		Wind Speed	19.50%
		Wind Direction	13.50%
		Visibility	11.50%
		Sky Conditions	7.50%
		Altimeter	1.50%
	Other:	Text (Open Ended)	Figure 6.2

Figure 6.2 represents a depiction of pieces of weather/tactical data received from Question 2 in the survey.

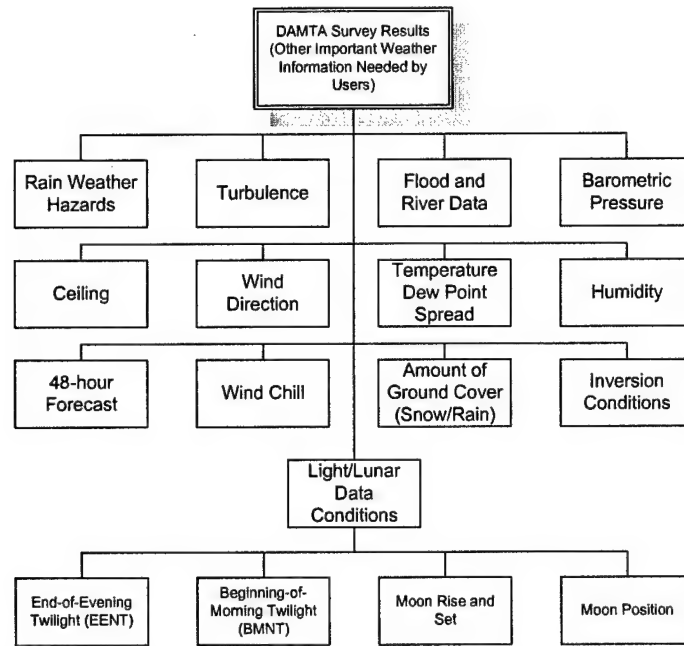


Figure 6.2 - Question 2 Open Responses Summary Diagram

Table 6.6 - DAMTA Survey Question 3 and Results

Figure 1 – Current Image

Figure 2 – Clear Day Image

Question	Possible Choices	Results
3. Rank order the battlefield functions on the right from most important to least important. Give the highest priority to functions that would be most benefited by the availability of digital images. Assume you are receiving 30-minute-old digital images (Figure 1, above) of locations within your Area of Concern from multiple weather collection systems. Assume that you have a clear-day image of the same view (Figure 2, above) to compare the current image against. Select the drop-down box corresponding to the appropriate number (Number 1 indicates the highest priority and most benefit).	Mission Planning	Average: 2.78
	Situational Awareness	Average: 2.82
	Decision-Making	Average: 3.30
	Information Gathering	Average: 3.83
	Survivability	Average: 4.22
	Lethality	Average: 5.20
	Sustainability	Average: 5.60

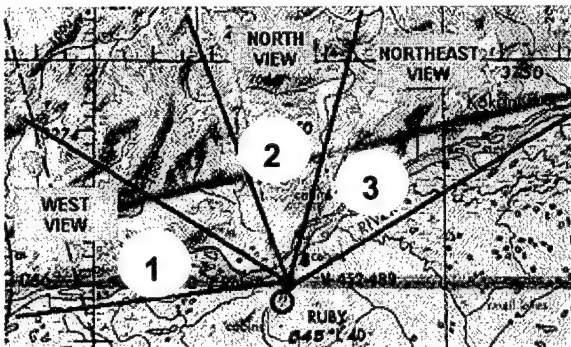
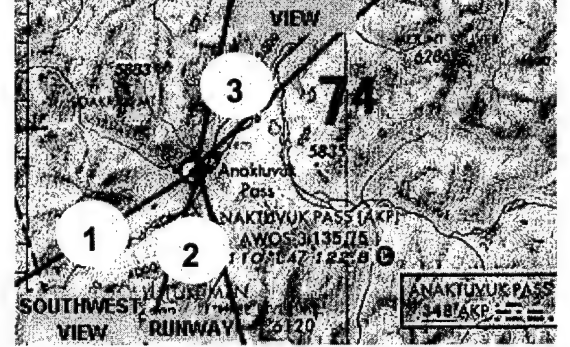
Table 6.7 - DAMTA Survey Questions 4-8 and Results

<i>Questions</i>	<i>Possible Choices</i>	<i>Results</i>
4. Pilots using imagery, as described above, have found that images help greatly to understand sky conditions, visibility, and ground conditions. What information from digital images would be most beneficial to you as a tactical leader on the battlefield? (Check all that apply.)	Current visibility (Fog, clear, haze, smoke)	73.50%
	Immediate terrain visualization (Local relief, general condition)	71.50%
	Current ground cover (Vegetation, trees, barren)	70.50%
	Current ground condition (Snow, mud, etc.)	67.00%
	Current precipitation (Snow, rain)	56.50%
	Weather effects on light conditions (Dark, bright, dawn, dusk)	52.00%
	Distant terrain visualization (Mountains, desert)	43.00%
	Current sky condition (Clear of clouds, overcast, type of clouds)	41.00%
5. Select the types of weather information that is important to your branch based on tactical situations that you had in the past?	Temperature	78.00%
	Visibility	77.00%
	Precipitation	72.00%
	Wind Speed	66.50%
	Wind Direction	59.50%
	Sky Conditions	34.50%
	Altimeter	20.50%
	None	0.00%
6. Control of the camera in order to possess a PAN (left to right movement) capability is important? (1 meaning strongly agree and 5 being strongly disagree)	1	Average: 1.920; Standard Deviation: 0.887
	2	
	3	
	4	
	5	
7. Control of the camera in order to possess a TILT (up and down movement) capability is important? (1 meaning strongly agree and 5 being strongly disagree)	1	Average: 2.205; Standard Deviation: 0.858
	2	
	3	
	4	
	5	
8. Control of the camera in order to possess a ZOOM (ability to magnify or reduce images) capability important? (1 meaning strongly agree and 5 being strongly disagree)	1	Average: 1.785; Standard Deviation: 0.956
	2	
	3	
	4	
	5	

Table 6.8 - DAMTA Survey Questions 10-11 and Results

<i>Questions</i>	<i>Possible Choices</i>	<i>Results</i>
10. Control of a camera requires increased bandwidth, and increases the probability of mechanical failure and detection by enemy forces; what is the value to you and your unit on control of the camera? Rank order the following scenarios (items a-c). Represent each scenario with a number from 1 to 3 with 1 being the best. Use only one number for each letter.	a. High control by user (Pan, tilt, zoom). High probability of loss of images or control within 30 days.	Average: 2.11
	b. Medium control by user (Pan only). Medium probability of loss of images or control within 30 days	Average: 1.54
	c. No control by user. Low probability of loss of images within 30 days.	Average: 2.37
11. Rank order the following camera attributes (items a-e). Represent each scenario with a number from 1 to 5 with 1 being the best. Use only one number for each letter.	a. Camera Redundancy (having more than one camera on a weather collection system; each camera points out in a different direction (e.g., northeast, north, west, south, etc.))	Average: 3.06
	b. Resolution (the clarity of picture for near and far objects)	Average: 2.17
	c. Field of View (the maximum angle that one camera can visually observe)	Average: 2.63
	d. Range (the maximum distance that one camera can visually observe)	Average: 2.79
	e. Overlap View (the percent coverage area that is mutually observed by more than one camera).	Average: 3.94

Table 6.9 - DAMTA Survey Questions 12-15 and Results

	
Figure 3: Three cameras oriented forward	Figure 4: Three cameras oriented forward and to the rear

Questions	Possible Choices	Results
12. Refer to Figures 3 and 4 (above). The weather collection systems will collect digital images, and a human will interpret the results at a remote terminal. Various camera configurations are currently being analyzed. Rank the configurations on the right in order from 1-3 (1 being the best) that you would prefer the most in regards to digital imaging.	Configuration 1: Three cameras with a 50-60 degree field of view for each camera. Cameras are forward oriented amounting to an almost 180-degree field of view (Figure 3). There is no distinguishable imagery distortion.	Average: 1.79
	Configuration 2: Three cameras with a 50-60 degree field of view for each camera. Cameras are both forward and rear oriented (Figure 4). There is no distinguishable imagery distortion.	Average: 1.86
	Configuration 3: One camera with a full 360-degree view capability using mirrors but delivers some distortion to the user.	Average: 2.30
13. A weather collection system with imagery would be very valuable to me and my unit? Select 1-5 with 1 being the best.	Average: 1.975	
14. How often do you believe that images would need to be updated to be tactically beneficial to you on the battlefield?	Every 30 minutes	27.00%
	Every hour	23.50%
	Every 3 hours	19.50%
	Every 6 hours	12.00%
	Every 5 minutes	10.50%
	Continually	7.50%
15. Do you feel a weather collection system with imagery would enhance your success on the battlefield?	Yes	82.00%
	Not Sure	16.50%
	No	1.50%

The survey respondents provided a number of written comments for questions 9, 16 and 17 (Table 6.10). Some representative comments from various personnel at USMA, along with appropriate explanations are provided in this section. The comments from Question 9 are depicted in the affinity diagram (Figure 6.3) and captures key terms and capabilities that users would like to have on DAMTA. Personnel answering question 9 included features or capabilities that would best be used within the entire DAMTA system including what and how the user interprets the digital imagery. Questions 16 and 17 (Tables 6.11 and 6.12, respectively) are illustrated by providing specific comments from personnel.

Table 6.10 - DAMTA Survey Questions 9, 16 and 17 and Results

9. What additional features or capabilities would you like to see on a battlefield digital imagery system being used to collect weather information?	Text (Open Ended)	Figure 6.3
16. How would a weather collection system with imagery best enhance your success on the battlefield?	Text (Open Ended)	Table 6.11
17. Do you have any other feedback you would like to share with us regarding a weather collection system or the benefits of imagery?	Text (Open Ended)	Table 6.12

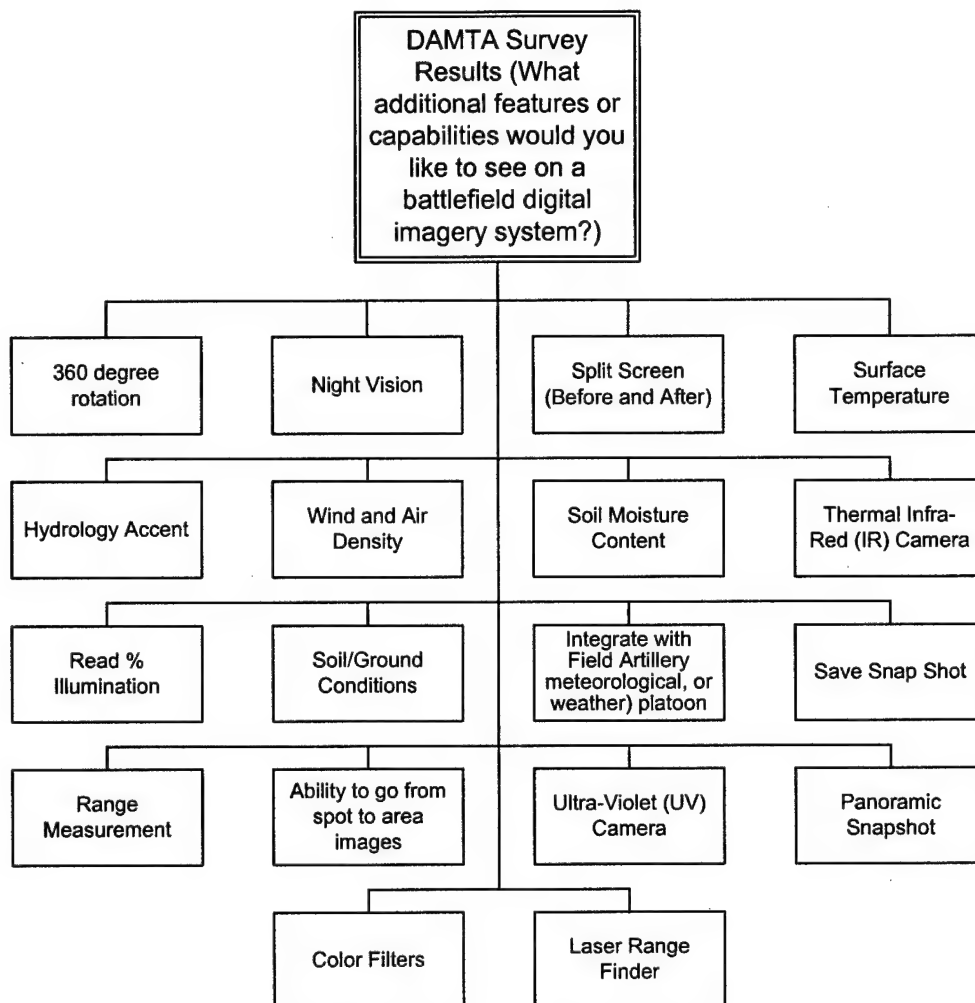


Figure 6.3 - Question 9 Open Responses Summary Diagram

Table 6.11 – Question 16 Results (Truncated)

Question 16 (How would a weather collection system with imagery best enhance your success on the battlefield?):		
<input type="checkbox"/>	For an ADA officer, this can put eyes on an AAA when you haven't enough assets to put a team on it. Other weather information will assist in quickly predicting WMD fallout fans (TBM carried).	Air Defense Artillery Officer
<input type="checkbox"/>	It provides a visual recon of the terrain and conditions we can expect. It may also serve as an early warning and target acquisition capability. Finally, it may allow us to see what we (terrain and forces) look like from the enemy's perspective, depending on placement.	Armor Officer
<input type="checkbox"/>	Weather conditions over varying terrain and short distances can cause an aviation mission to fail; the ability to see the conditions with which you must fly is an exceptional tool.	Aviation Officer
<input type="checkbox"/>	Would result in real time weather reporting. Often the USAF Wx teams are not able to cover all areas of interest. This would augment the Wx teams and Pilot Reports currently being used.	Aviation Officer
<input type="checkbox"/>	As an NBC officer, accurate and timely Wx info are imperative... same with smoke especially wind speed, direction, temp gradient.	Chemical Officer
<input type="checkbox"/>	Weather of course affects the flight of an artillery round. Computer-generated firing data can account for non-standard weather conditions, especially when sensors can accurately measure current weather conditions.	Field Artillery Officer
<input type="checkbox"/>	The type of imagery you mention seems like it would allow us to plan then use "hard copy" images for rehearsals, briefbacks, etc. With some sort of update capability of 12 hours or less, we can even see how things are changing in the AO. Much like some flight simulators, we could get very close to rehearsals on the real ground we're going to operate on and we can include anticipated weather impacts.	Infantry Officer
<input type="checkbox"/>	Provide near real-time, high-resolution imagery of objective for mission planning & rehearsal.	Engineer Officer
<input type="checkbox"/>	The imagery capability would be critical for planning ground maneuver (route planning, SBF selection, etc).	Infantry Officer
<input type="checkbox"/>	By giving me a display of weather effects on the terrain that I'm planning operations on. (ie) is current precipitation causing local flooding that would slow down movement; is wind direction consistent; etc.	Infantry Officer
<input type="checkbox"/>	Must be interoperable with Joint Platforms. Typically, satellite collection will only provide 1km scale resolution. How will 1KM imagery be portrayed on a 1:25,000 scale tactical map?	Infantry Officer
<input type="checkbox"/>	Improving situational awareness so that feasibility of mission plans could be assessed both during planning and execution phases.	Military Police Officer
<input type="checkbox"/>	Dealing with Chemical Munitions (I'm an EOD guy) both in terms of wind speed/direction and temperature that will effect both evaporation and the time my soldiers can spend in MOPP4	Ordnance Officer
<input type="checkbox"/>	Weather data not nearly as important as the digital images for recon purposes	Signal Officer
<input type="checkbox"/>	Visibility provides planning and decision making for logistics movements; terrain accessibility, soft areas, weather influence over terrain, etc.	Transportation Officer

Table 6.12 - Question 17 Results (Truncated)

<p align="center"><i>Question 17</i> <i>(Do you have any other feedback you would like to share with us regarding a weather collection system or the benefits of imagery?):</i></p>	
<input type="checkbox"/> The digital imagery won't help ADA anymore than a radar but wind and air quality information can give better information than a chemical downwind message for chemical hazard plotting.	Air Defense Artillery Officer
<input type="checkbox"/> Great idea, but only if you can put these cameras in remote locations not readily available to human observation; if I can see it from the ground, I don't need your camera.	Aviation Officer
<input type="checkbox"/> The update time could be variable depending on the ambient conditions. If the weather and situation are static, then a slower update is all that is needed. If dynamic and changing, then I want a constant update. It would also be nice to have a direct feed of temperature and wind speed/direction into the artillery computer system used to compute firing data.	Field Artillery Officer
<input type="checkbox"/> The update time could be variable depending on the ambient conditions. If the weather and situation are static, then a slower update is all that is needed. If dynamic and changing, then I want a constant update. It would also be nice to have a direct feed of temperature and wind speed/direction into the artillery computer system used to compute firing data.	Field Artillery Officer
<input type="checkbox"/> Should be useful for solving artillery MET ballistic corrections.	Field Artillery Officer
<input type="checkbox"/> From FA perspective, weather data more important than imagery.	Field Artillery Officer
<input type="checkbox"/> To be a "battlefield system", need to think about how attributes of the system will be affected by modifications that must be made to make it deliverable and survivable on the battlefield.	Engineer Officer
<input type="checkbox"/> The current tactical comms are not compatible with satellite comms. It would be nice to get one digital image that is synched from the S-2 Intel Sitrep, with the S-3 Ops Sitrep and the environmental awareness overlay. The problem will be in message formats from joint satellites to tactical units at a scale that is useful to individual soldiers. Since a soldier will use a screen with much fewer pixels than one in a TOC, how will zooming not become very pixilated?	Infantry Officer
<input type="checkbox"/> I would rather have a system that was able to find the enemy whose by product was weather information.	Infantry Officer
<input type="checkbox"/> It would be revolutionary, but would also lead to a false sense of security. As described it is extremely limited because the system is visual only. This means that in times of low light, low visibility it would be relatively useless. If employed within proximity of friendly troops as a physical security enhancing measure then the system needs to be day/night, no visibility/low visibility and thermal capable AS WELL AS standard digital video. Sector scans need to be programmable by the operator to allow maximum flexibility in response to the endless possibilities terrain presents. Once programmed they would essentially operate automatically, kind of like a radar. This automatic function will reduce operator interference and increased maintenance due to user use. The operator needs to be prompted for movement, or other factors (large metal objects) increase in heat signatures etc... The sectors or orientation of the camera needs to be adjustable to allow the emplacing element to modify due to terrain restrictions and limitations (OCOKA). System needs to be able shielded to allow continuous uninterrupted transmission and needs to be redundant.	Military Intelligence Officer
<input type="checkbox"/> The pictures should be available to a wide range of users, not just the SWO and Cdr. The targeting officer, fwd observer, scout plt leader, S2, etc. These systems should be treated as OPs and be used to cover key terrain, DPs, TAIs and NAIs.	Military Intelligence Officer
<input type="checkbox"/> Perhaps a soil/terrain assessment tool could aid in determining mobility in the area (soil density, softness, rocks, etc.)	Transportation Officer

6.1.2 Analysis of Survey Results (Questions 1-8 & 10-15).

Question 1 *Which tactical weather information sources have you used in the past either in training or real-world army missions?*

This question determined a basis for what weather resources were used by the respondents. Most of the respondents used Human Assets (67.50%) or a broad range of Intelligence Assets (66.50%) as a means to gain tactical weather data (Figure 6.4). Sensors like collection resources are new to the battlefield as a collection resource but received almost 25% usage among the 200 respondents. Figure 6.5 illustrates the use of weather collection sources by branch. Each branch relies on a different set of collection resources. Chemical, Aviation and Armor branches rely on Human Assets more than any of the other branches.

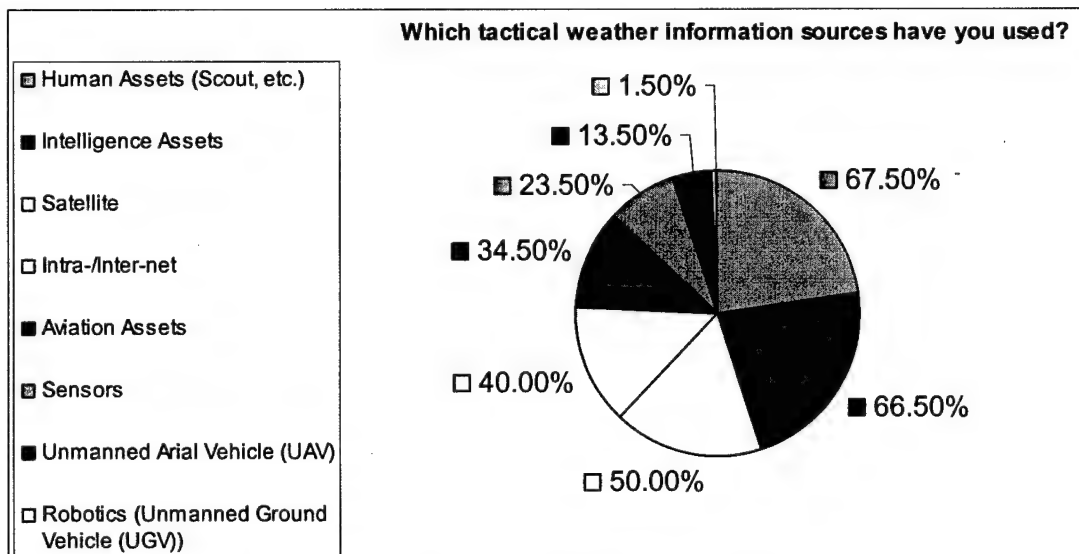


Figure 6.4 - Weather Information Sources used by Respondents (Question 1)

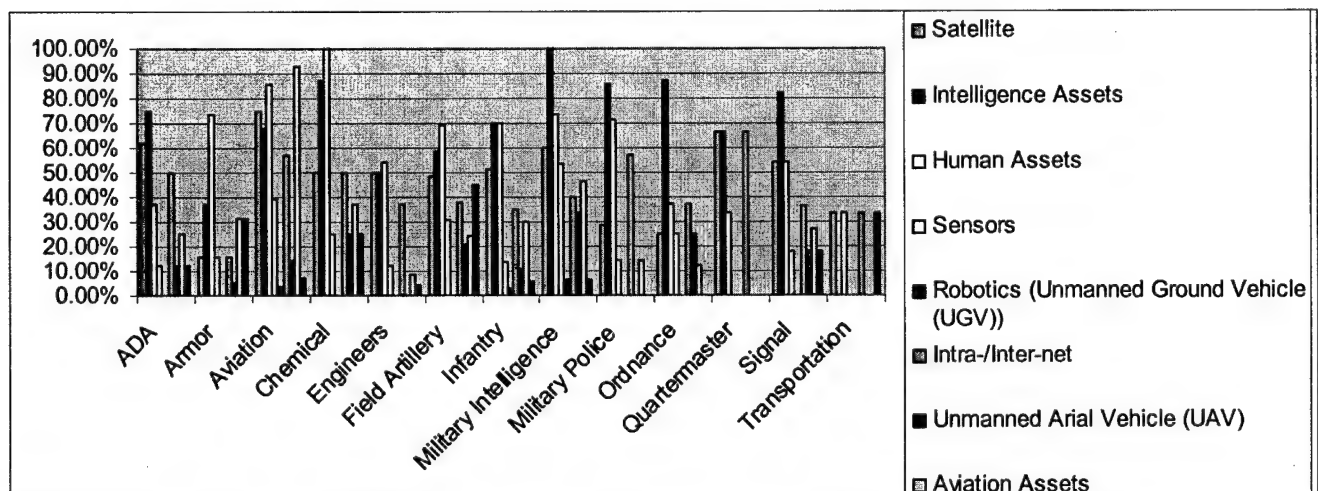


Figure 6.5 - Weather Information Sources used by Army Branches (Question 1)

Question 2 *Select the two most important pieces of weather information based on the benefits it would provide you as a tactical leader.*

This question sought to determine the most important piece of weather data for users. Figure 6.6 identifies the most important piece of weather data for most branches were Visibility (45.00%) followed by Precipitation (18.50%) and Temperature (12.50%). Precipitation (and its effects to terrain), which was the second most important piece of weather data, was confirmed as important when asked in the second part of this question (23.50%). Temperature and Wind Speed were also important to respondents (Figure 6.7) as the second most important data items. Analysis of specific branches concluded that the Engineers need precipitation data; Aviation need Visibility data; Field Artillery need Wind Speed data, and Infantry need Visibility and Temperature data.

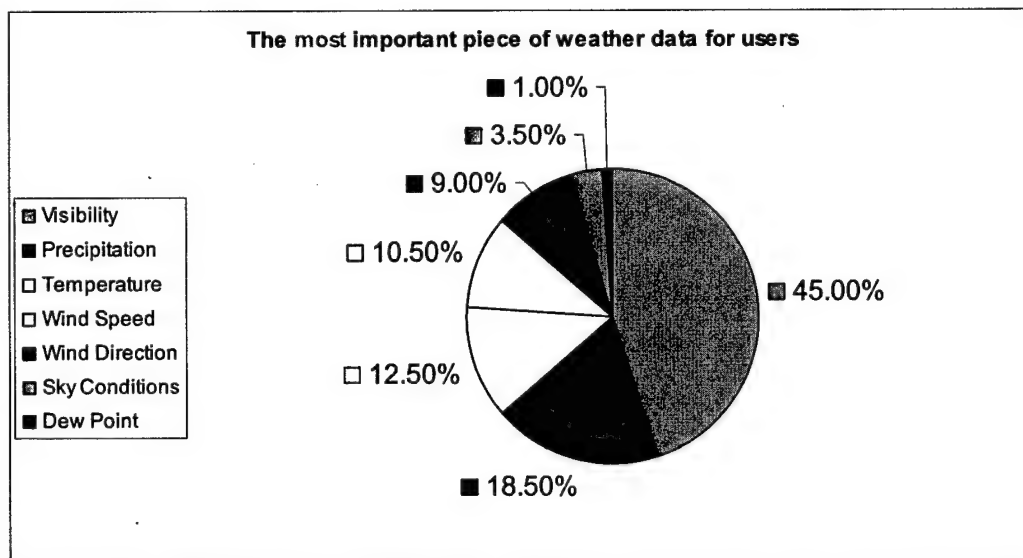


Figure 6.6 - Most Important Weather Data for users (Question 2)

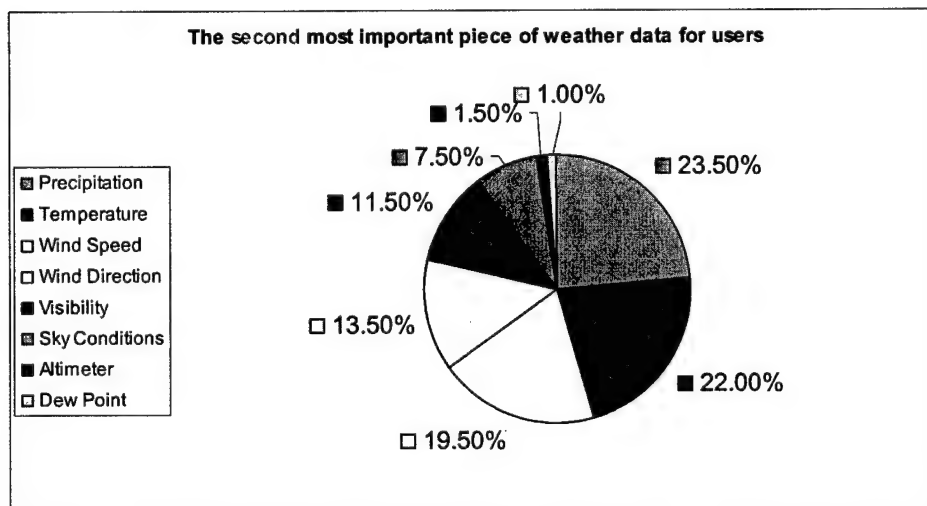


Figure 6.7 - Second Most Important Weather Data for users (Question 2)

Question 3 Rank order battlefield functions from most important to least important. Give the highest priority to functions that would be most benefited by the availability of digital images.

Respondents were given two figures as reference images and a time period for imagery updates. Overall respondents thought that digital imagery would have the most impact on “Mission Planning,” “Situational Awareness,” and “Decision Making” on the battlefield, respectively. Figure 6.8 depicts the importance of seven battlefield functions (lower number on the y-axis equates to more importance). The deviation for each battlefield function is approximately the same and does not render more analysis. Figure 6.9 shows the battlefield functions as selected by branch. One of the outliers were the Quartermaster branch selected “Survivability” and “Sustainability” as a critical battlefield function for digital imagery but did not think “Information Gathering” was very important. Other highlights from Figure 6.9 are Armor thought that “Situational Awareness” was very important; Signal thought “Survivability” was important and Military Police thought “Decision Making” was important. In summary, branches have specific battlefield strengths based on their skill set and weather/intelligence collection resources and tend to pick battlefield functions based on those parameters.

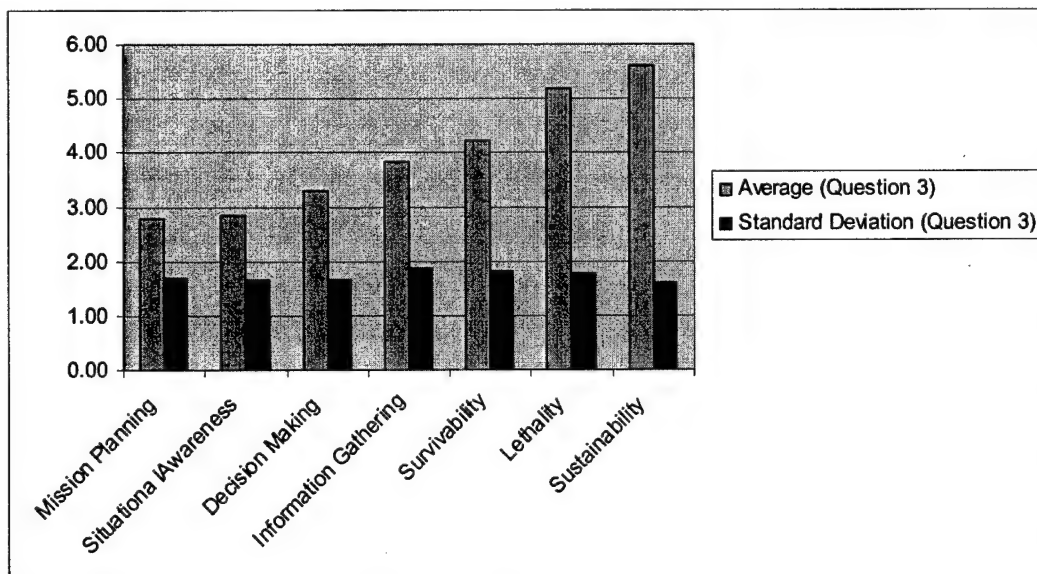


Figure 6.8 - Battlefield Functions selected by Respondents {Importance from left to right} (Question 3)

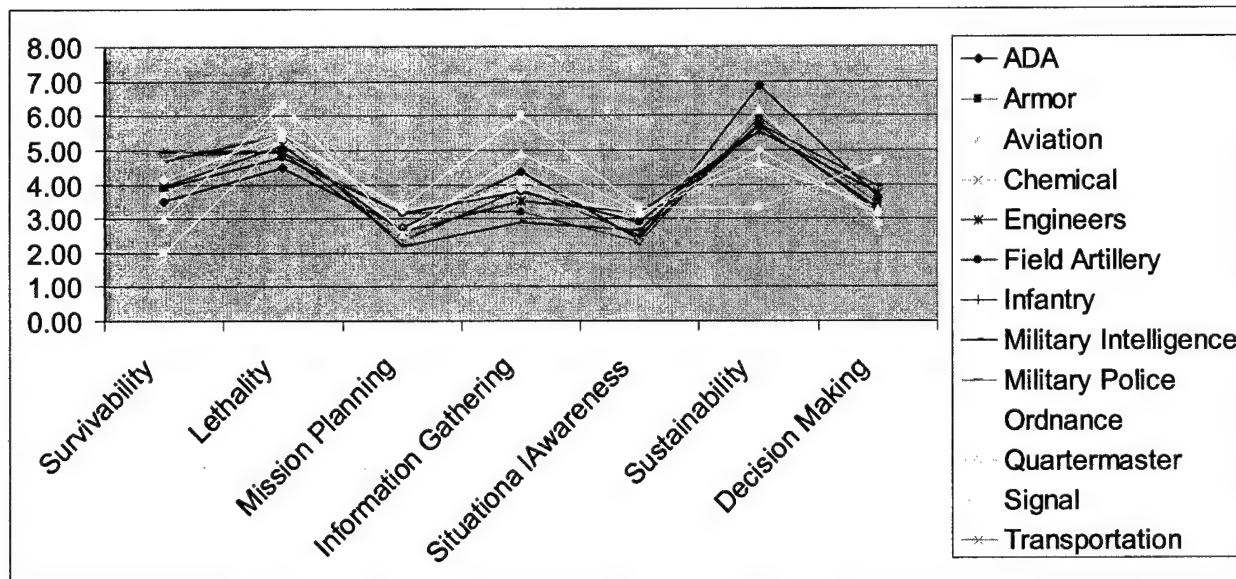


Figure 6.9 - Battlefield Functions selected by Branch (Question 3)

Question 4 *Pilots using imagery have found that images help greatly to understand sky conditions, visibility, and ground conditions. What information from digital images would be most beneficial to you as a tactical leader on the battlefield?*

This question sought to determine the critical and most beneficial information that digital imagery could provide for users. Current visibility (fog, clear, haze, smoke), Immediate terrain visualization (local relief, general condition), Current ground cover (vegetation, trees, barren) and Current ground condition (snow, mud, etc.) were the most critical four bits of information for users receiving 73.50%, 71.50%, 70.50% and 67.00%, respectively (Figure 6.10). This question provided correlation with question 2, which asked what information was most important to users if digital imagery could be provided. Again, visibility is a critical piece of information for users of all branches.

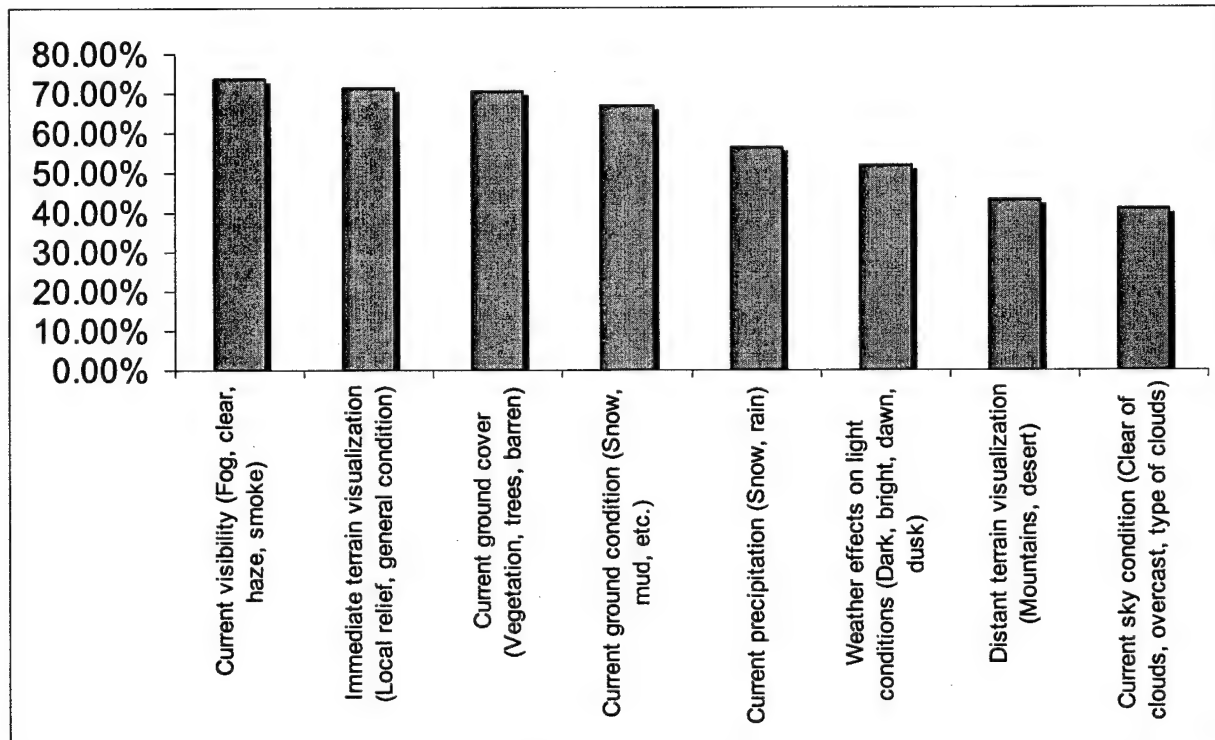


Figure 6.10 - Weather Information Chart (Question 4)

Question 5 *Select the types of weather information that is important to your branch based on tactical situations that you had in the past?*

This question sought to determine the most important pieces of weather data by providing a distribution of 7 types of data. This question was also used to verify data in Question 2, which asked what the top two pieces of weather were. Overall, most of the respondents felt that Temperature (78%), Visibility (77%) and Precipitation (72%) were critically important (Figure 6.11).

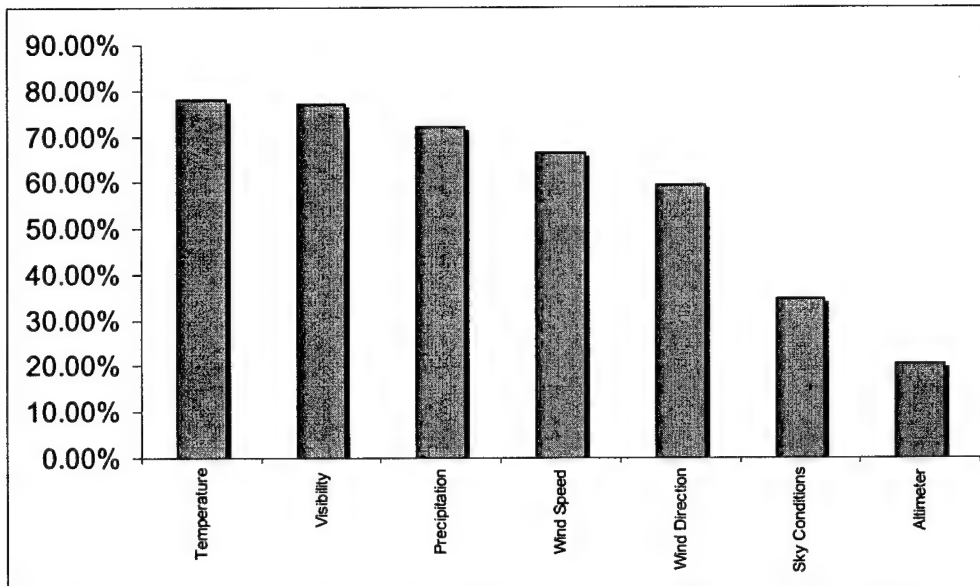


Figure 6.11 - Percent Responding to Weather Data Importance (Question 5)

Questions 6, 7, and 8 simply asked individuals to rate the importance of 3 digital imagery device capabilities (PAN, TILT, and ZOOM) from 1-5, where 1 was “Strongly Agree (Very Important)” and 5 was “Strongly Disagree (Not very Important)” with 3 equating to “No Opinion or Don’t Know.”

- ❑ Question 6 *Control of the camera in order to possess a PAN (left to right movement) capability is important (1-5)?*
- ❑ Question 7 *Control of the camera in order to possess a TILT (up and down movement) capability is important (1-5)?*
- ❑ Question 8 *Control of the camera in order to possess a ZOOM (ability to magnify or reduce images) capability important (1-5)?*

Overall, respondents felt that the *zoom* capability was the most important function of a future device followed by *pan* and *tilt* (Figure 6.12). The standard deviation for the *zoom* capability was also high which alludes to a wide variance between respondents. Most respondents were consistent placing *tilt* as the least important of the capabilities (Figure 6.13). We also felt that respondents for this question were selecting a capability based on a tactical scenario and not a weather collection scenario alone.

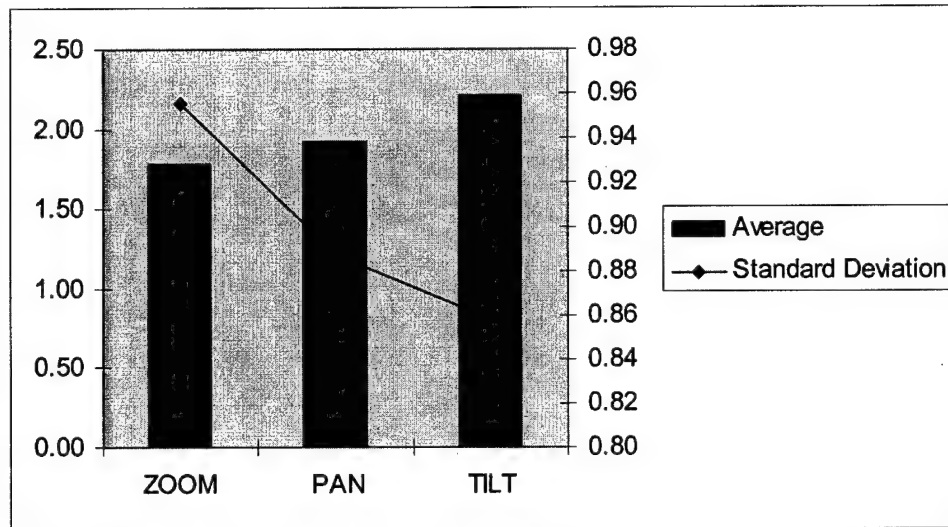


Figure 6.12 - Imagery Device Capability Chart (Question 6, 7, 8)

Figure 6.13 provides an overall view of the 3 capabilities on a score line and represents *zoom* and *pan* as capabilities important to the respondents. Only three branches (Air Defense Artillery, Armor and Aviation) or 23% of the branches surveyed found that *zoom* and *tilt* were both important as seen with a small separation between their averages. Table 6.13 displays the selection rate by branch for the imagery capabilities and correlates the notion that *tilt* is not very important when compared to the others.

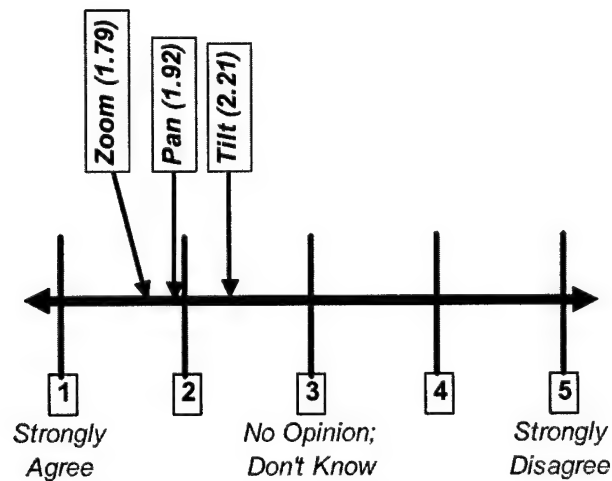


Figure 6.13- Score Line for Imagery Device Capabilities (Question 6, 7, 8)

Table 6.13 - Selection Rate by Branch for 3 Camera Control Attributes

	ZOOM	PAN	TILT
Selected the most important	10	3	2
Selected the second most important	3	10	1
Selected the third most important	0	0	10

Question 10 *Control of a camera requires increased bandwidth, and increases the probability of mechanical failure and detection by enemy forces; what is the value to you and your unit on control of the camera?*

Individuals were asked to rank order a set of 3 camera control mechanisms (policies listed below). This question provided insights into the amount of control that users wanted to see with a digital imagery device on the DAMTA platform.

- ☐ High control by user (Pan, Tilt, Zoom). High probability of loss of images or control within 30 days.
- ☐ Medium control by user (Pan only). Medium probability of loss of images or control within 30 days.
- ☐ No control by user. Low probability of loss of images within 30 days.

Figure 6.13 shows that on average most respondents want some control of the imagery device (*Medium Control*) even if that increases the detection of the device and mean time to failure (MTTF). *Medium Control* averaged a 1.5 with the lowest standard deviation compared to the other policies (*No Control* and *High Control*). Figure 6.14 depicts a score line of all three policies. 49.5% (99 out of 200) of the respondents chose *Medium Control* as the best policy option compared to 29.5% and 21.0% for *High* and *No Control* options, respectively. Analyzing data across all 13 branches surveyed; all 13 on average selected *Medium Control* as the most important policy option (Table 6.14).

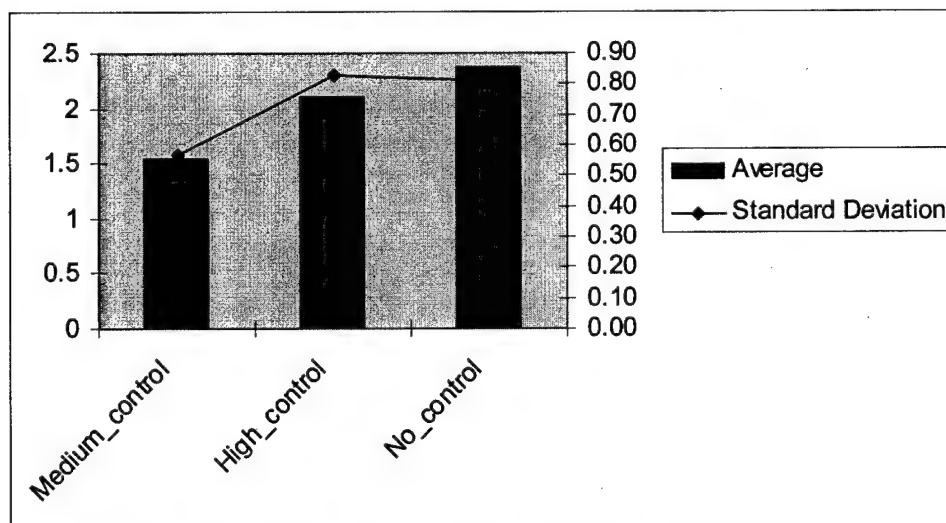


Figure 6.14 - Imagery Device Policies Selection Chart (Question 10)

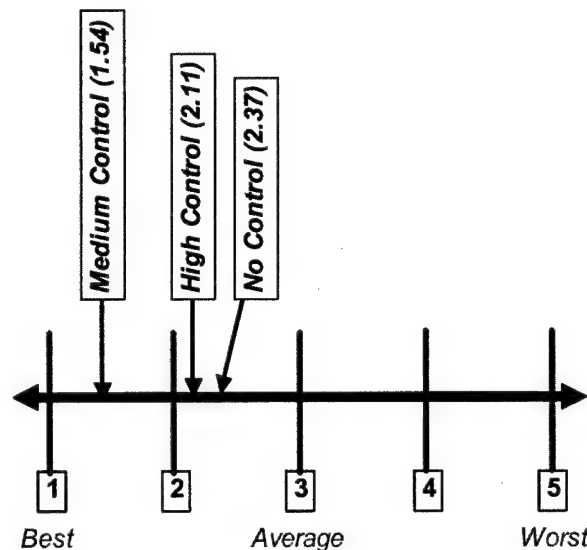


Figure 6.15- Score Line for Imagery Device Policy (Question 11)

Table 6.14 - Selection Rate by Branch for 3 Control Policies

	Medium Control	High Control	No Control
Selected the most important	13	1	0
Selected the second most important	0	9	4
Selected the third most important	0	3	9

Question 11 Rank order the following camera attributes (listed below). Represent each scenario with a number from 1 to 5 with 1 being the best.

Individuals were asked to rank order a set of 5 system integration attributes and concerns. This question provided insights into the trade-off values for individuals in terms of digital imagery configurations on the DAMTA platform.

The weather collection system collects digital images, and a human interprets the results at a remote terminal. Because there is a human-in-the-loop, these trade-offs are potentially correlated to the *trust* that users (commanders and decision makers) place in the DAMTA system and its images.

- ☐ Camera Redundancy (having more than one camera on a weather collection system; each camera points out in a different direction (e.g., northeast, north, west, south, etc.)
- ☐ Resolution (the clarity of picture for near and far objects)
- ☐ Field of View (the maximum angle that one camera can visually observe)
- ☐ Range (the maximum distance that one camera can visually observe)
- ☐ Overlap View (the percent coverage area that is mutually observed by more than one camera).

Figure 6.16 represented the five-system integration attributes and is arranged in importance from left to right. Resolution is the most important attribute on average followed by Field of View and Range. The standard deviation is consistent for all but Camera Redundancy where certain branches (Quartermaster and Transportation) placed a high importance on this attribute on average. Resolution was selected as the most important attribute 37.0% of the time (74 out of 200 respondents).

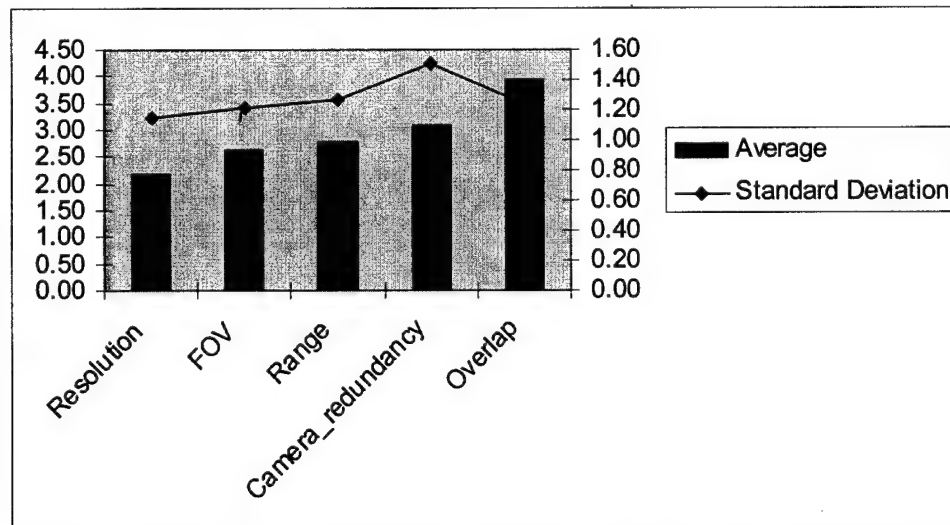


Figure 6.16 - Imagery Device Attributes Selection Chart (Question 11)

Figure 6.17 plots the average score for each attribute verses each of the 13 branches. *Overlap* is consistently the least important attributes except in the cast of Air Defense Artillery and Armor. Other analysis yield the following comments based on Figures 6.17 and 6.18 and Table 6.15:

- *Field of View* is important on average to Chemical, Engineers, Ordinance, Quartermaster and Transportation branches (5 branches) and selected by 3 other branches as second most important (Armor, Infantry and Signal).
- 9 out of 13 branches selected *Range* as the second most important attribute on average.
- *Redundancy* and *Field of View* was very important to Quartermaster.
- 8 out of 13 branches selected *Resolution* as the most important with another 3 selecting as the second most important attribute.

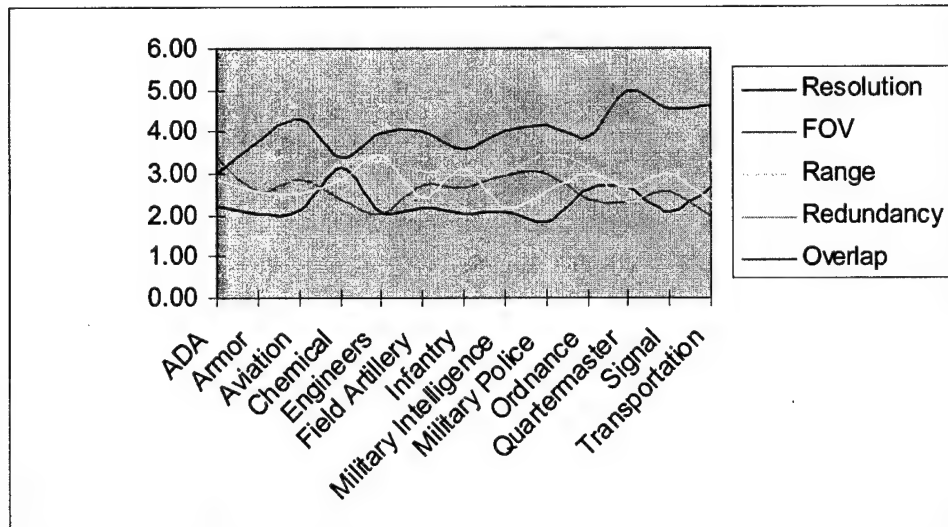


Figure 6.17 - Imagery Device Attributes Selection Chart by Branch (Question 11)

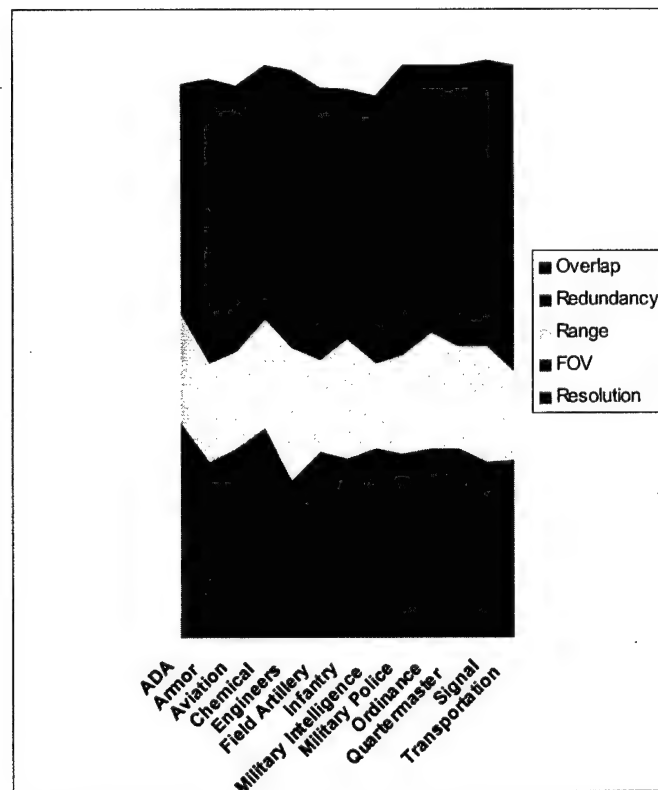


Figure 6.18 - Imagery Device Attributes Selection Area Chart by Branch (Question 11)

Table 6.15 – Level of Attribute Importance

	Resolution	FOV	Range	Redundancy	Overlap
Selected the most important	8	5	0	1	0
Selected the second most important	3	3	9	1	0

Question 12 Rank the configurations listed below from 1-3 (1 being the best) that you would prefer the most in regards to digital imaging.

The individuals were given two figures for configuration 1 and 2 (reference previous section and Appendix B). Configuration 3 depicts a new technology called the panoramic 360-degree view camera where one camera with many mirrors gives users a 360-degree view. This solution uses a parabolic mirror to capture the 360° scene in each frame, but the curvature of the non-planar mirrors causes astigmatism distortion [Johnson, 1998]. Johnson [1998] lists several other potential alternatives that give users a panoramic view.

- ❑ **Configuration 1:** Three cameras with a 50-60 degree field of view for each camera. Cameras are forward oriented amounting to an almost 180-degree field of view (Figure 3). There is no distinguishable imagery distortion.
- ❑ **Configuration 2:** Three cameras with a 50-60 degree field of view for each camera. Cameras are both forward and rear oriented (Figure 4). There is no distinguishable imagery distortion.
- ❑ **Configuration 3:** One camera with a full 360-degree view capability using mirrors but delivers some distortion to the user.

Figure 6.19 and Figure 6.20 depict the importance placed on Configuration 1 and Configuration 2. On average (1.79) more value is placed on Configuration 1 (Forward Looking Cameras; 180 degree view) compared to 1.89 and 2.30 for All Around View and Panoramic View, respectively. This correlates to the value users place on resolution (See Question 11) and visibility (See Question 2). 45.5% of the respondents (Figure 6.20) chose forward looking cameras but analysis by branch shows that Configuration 1 and 2 are nearly equal with both having a standard deviation of 0.31. 43% and 50% of the branches chose three cameras forward and three camera all around as the most important configuration, respectively. Configuration 2 and 3 minimizes the need for *pan* capability but configuration 2 has better resolution than configuration 3. Based on this analysis, we feel this is the best configuration for the DAMTA platform.

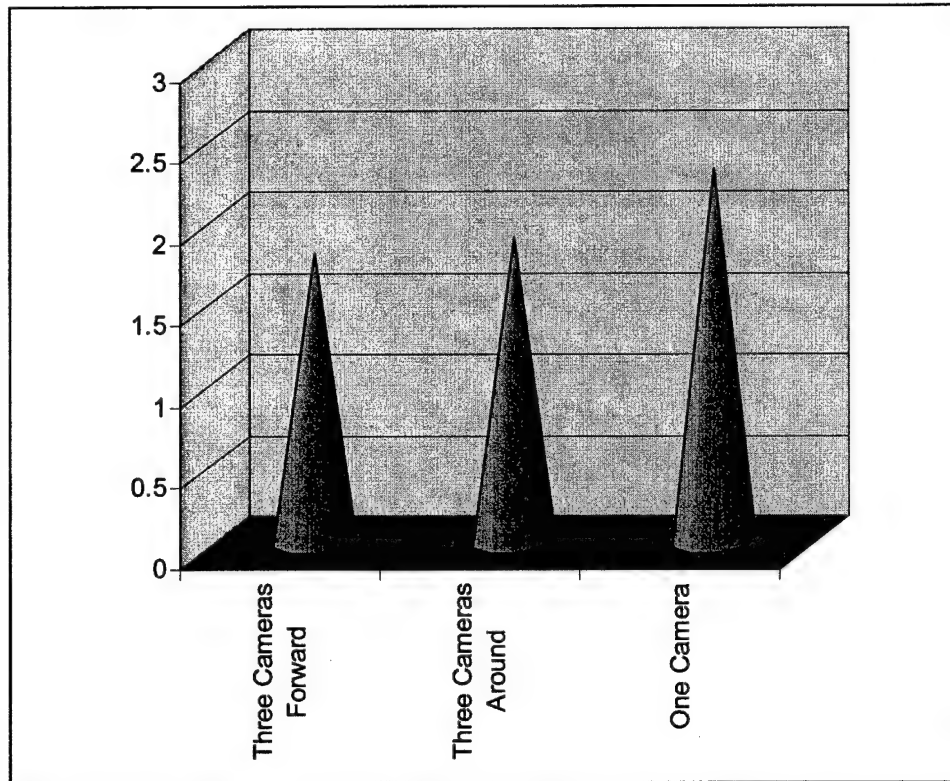


Figure 6.19 - Imagery Device Configuration Importance Average Chart (Question 12)

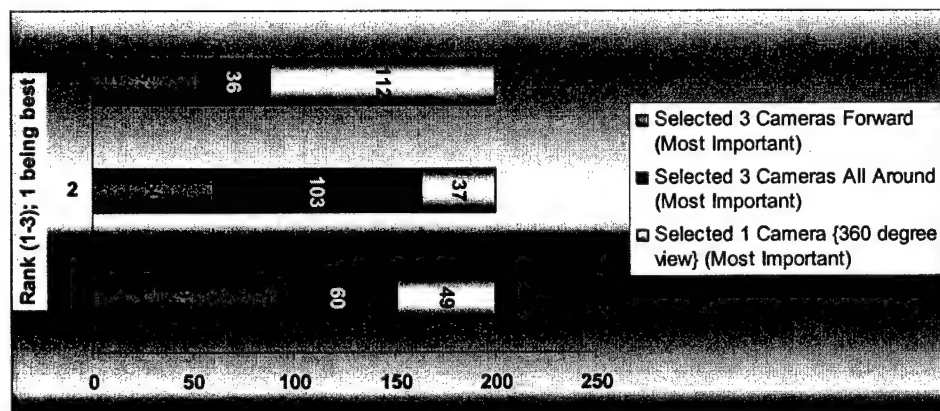


Figure 6.20 - Imagery Device Configuration Importance Bar Chart (Question 12)

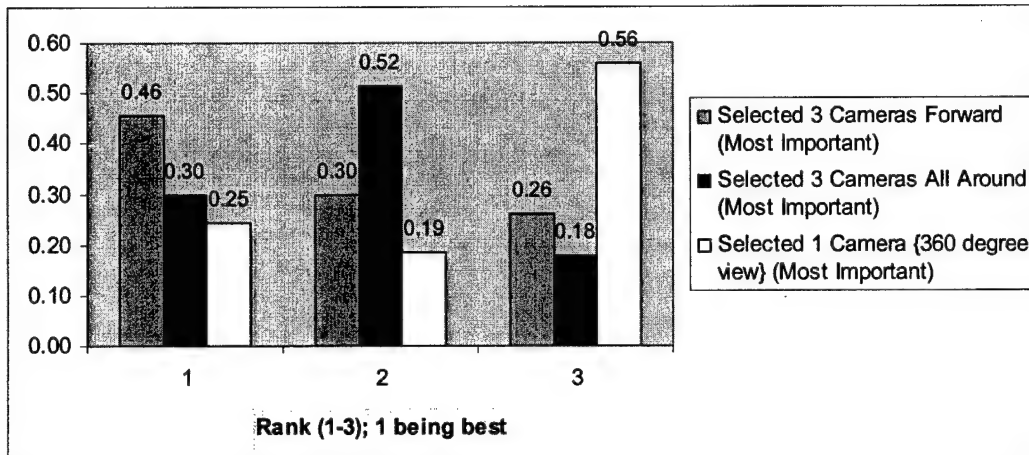


Figure 6.21 - Imagery Device Percentage Selecting the three Configurations (Question 12)

Question 13 *A weather collection system with imagery would be very valuable to my unit and me?*

This question investigated the value and usability of the digital imagery with the DAMTA platform. Individuals were asked to rate digital imagery within a weather collection system from 1 to 5 with 1 being very valuable. Overall users thought the imagery is a valuable asset on the DAMTA platform with an average score of 1.975. The average for all branches was 2.06 with a standard deviation of 0.83 (Table 6.16). Based on the histogram (Figure 6.21) most respondents selected either 1 (very valuable) or 2 (almost very valuable).

Table 6.16 – Branch Average Value Level

Branch	AVG	SD
Aviation	1.43	0.74
Military Police	1.43	0.53
Military Intelligence	1.67	0.82
Infantry	1.84	0.87
Transportation	2.00	1.00
Chemical	2.13	0.83
Ordinance	2.13	0.83
Engineers	2.17	0.96
Field Artillery	2.17	0.80
Armor	2.26	0.73
Signal	2.36	0.81
ADA	2.50	0.76
Quartermaster	2.67	1.15
AVERAGE	2.06	0.83

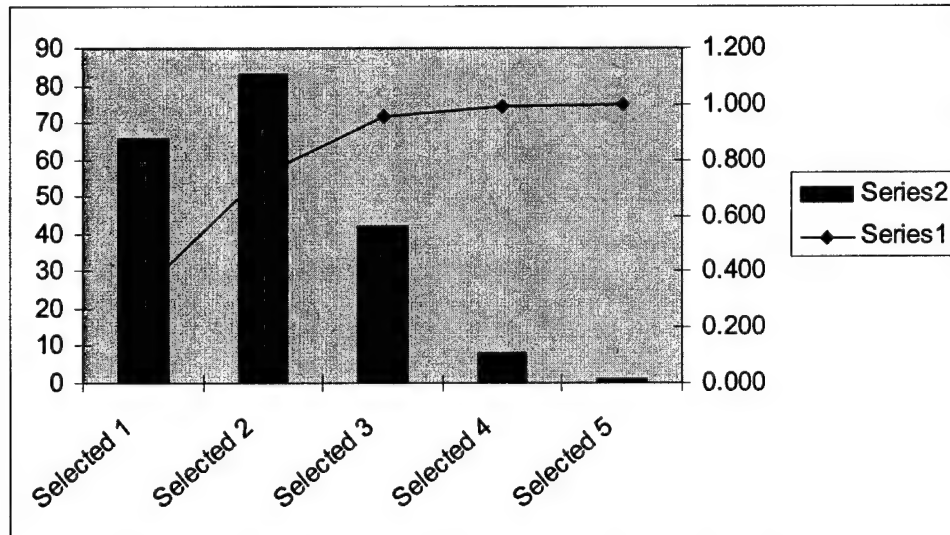


Figure 6.22 - Histogram of Respondents Choices (Question 13)

Figure 6.22 depicts (from left to right) the branches of the Army and value they put on imagery on a weather collection device. Aviation, Military Police and Military Intelligence place a high value of digital imagery while Air Defense Artillery and Quartermaster place a very low value on average. The red line at 0.83 illustrates the average standard deviation across all of the 13 branches. Any bar above that line indicates a high variance of answers among that specific branch. For example, Quartermaster yields a high variance among the respondents answering this question.

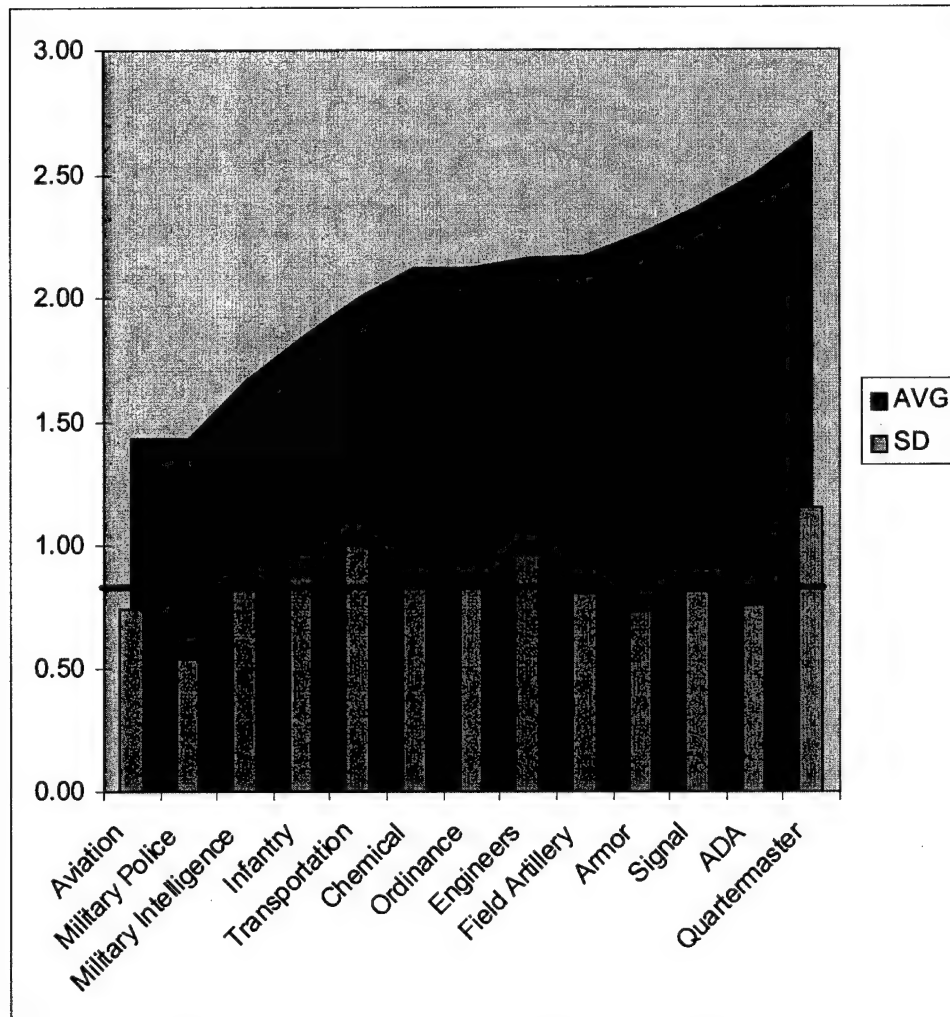


Figure 6.23 - Order of Value of Imagery for Branches

Question 14 *How often do you believe that images would need to be updated to be tactically beneficial to you on the battlefield?*

This question investigated the length of time users require imagery updates on the battlefield. Based on the histogram (Figure 6.23) “Every 30 minutes” and “Every hour” received 27.0% and 23.5% of the survey results, respectively. Over 50% feel that digital images are useful if updated within 60 minutes. Less than 10% feel that digital images should be updated continually.

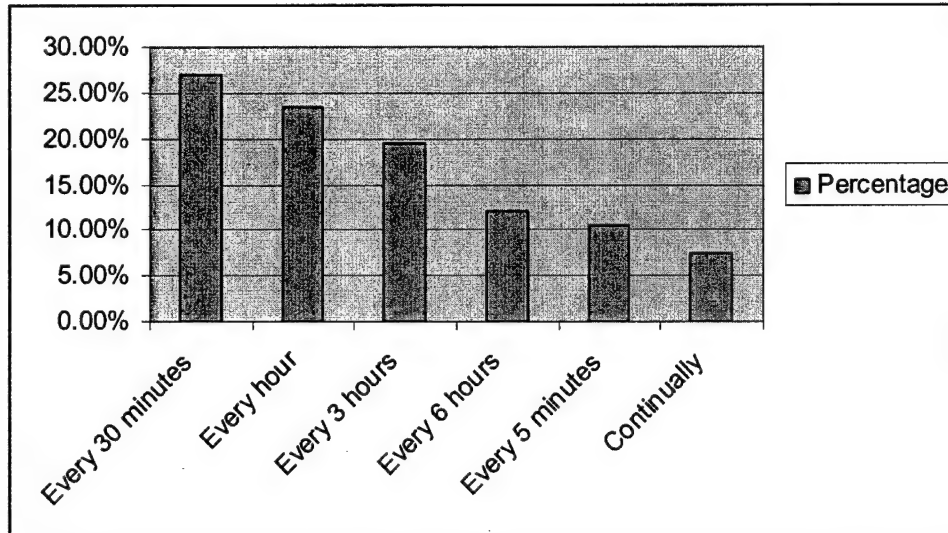


Figure 6.24 - Histogram of Digital Imagery Update Timeline (Question 14)

Question 15 *Do you feel a weather collection system with imagery would enhance your success on the battlefield?*

This question investigated the overall usefulness, and value of our project in relationship to providing digital imagery on the DAMTA platform and as an enhancement to weather data collection. Figure 6.24 shows that 82% of the respondents felt imagery would enhance their success on the battlefield within a weather and tactical information collection system. 16.50% were not sure and only 1.5% felt that this system would not enhance their success on the battlefield.

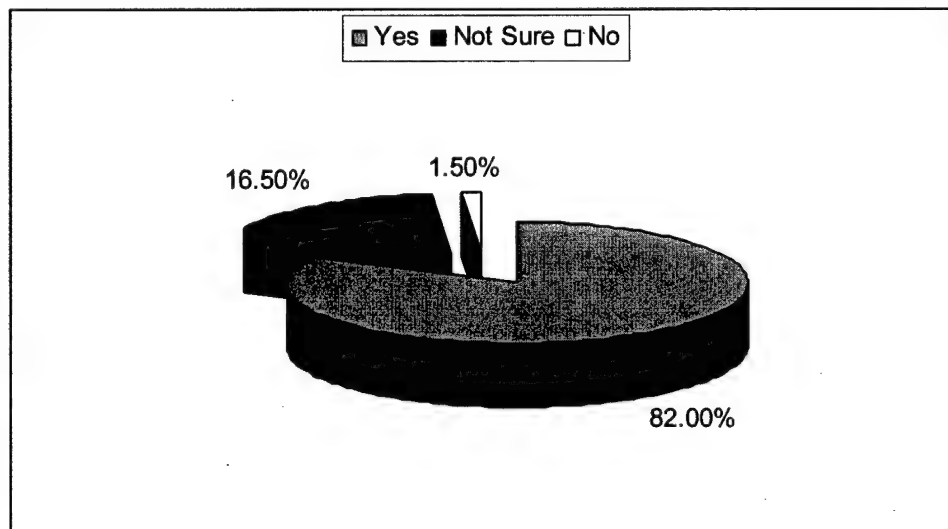


Figure 6.25 – Impact on Success from Imagery Integration with a Weather Collection System

An affinity diagram depicting the most important objectives from the survey results to date is illustrated in Figure 6.25. This diagram helps us understand the major objectives of the stakeholders and define the boundaries of our system.

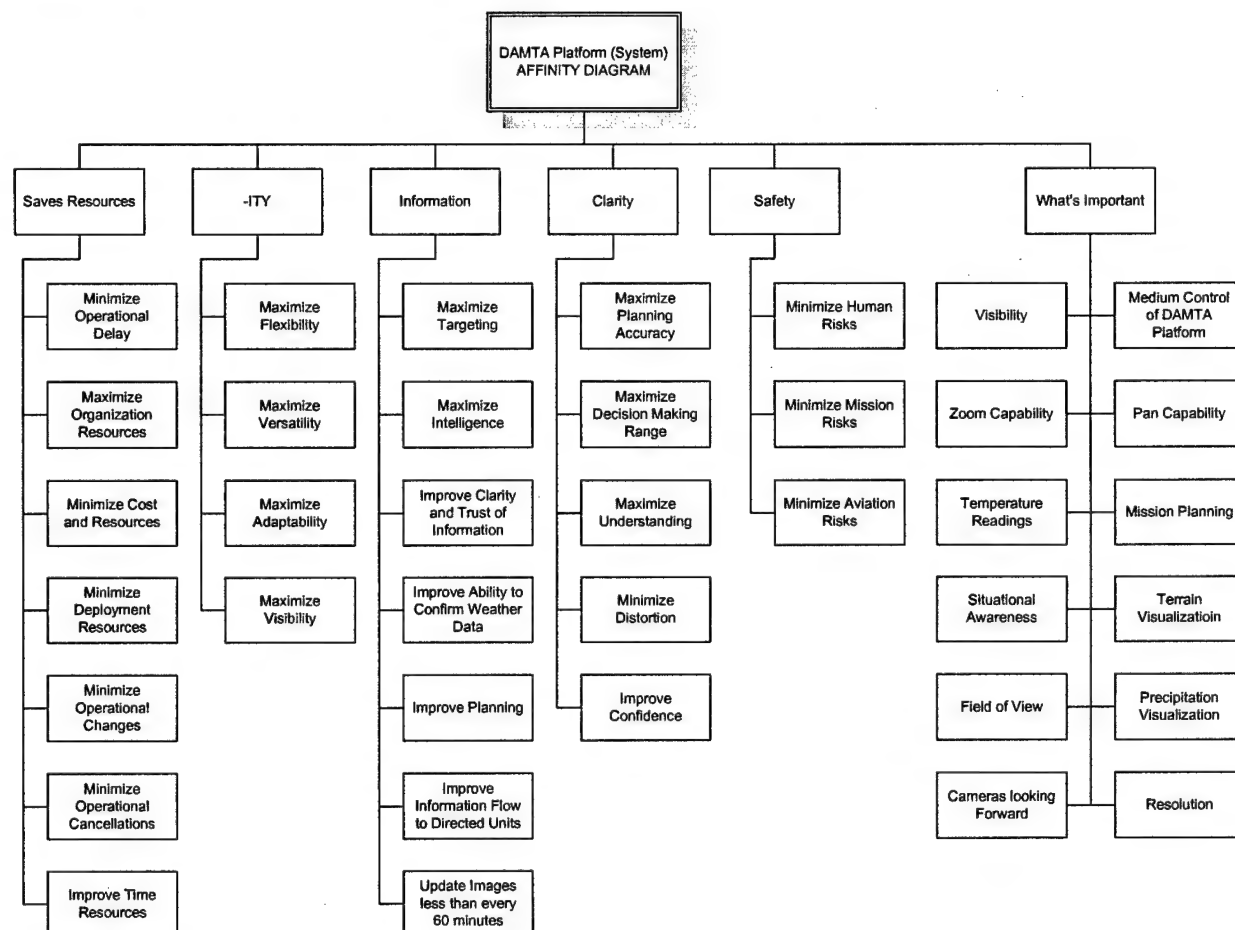


Figure 6.26 - DAMTA Affinity Diagram

6.2 Methods of Employment. There are several factors that are relevant to the problem of employing sensor systems on the battlefield including delivery methods (type), objectives of the stakeholders, and the metrics to measure the advantages and disadvantages of each method. Table 6.17 illustrates the possible methods of sensor employment. Based on the size and shape of the current DAMTA platform, only certain methods can be used to deliver the platform (highlighted with an asterisk in column 1 of Table 6.17). In most cases (excluding hand emplacement), the DAMTA platform will be delivered with a parachute delivery system. For example, a C130, C141 or C17 could drop the platform over the intended area and DAMTA would then self deploy and start its weather collection and other intended functions. Columns 3-10 of Table 6.17 represent the objectives (considerations) that affect stakeholders' employment method decisions. Stakeholders will make decision based on these considerations and the

feasibility of implementing the delivery system. For example, it is unlikely that a UAV, or some type of floating mechanism such as a hot air balloon would be a feasible alternative based on availability and some of the other objectives listed in Table 6.17. An 'X' in the table indicates that the objective is an advantage for that emplacement alternative based on our assessments and past research in this area.

The last two columns in Table 6.17 represent the advantages and disadvantages of the method of employment have over other methods. Like the airplane employment mechanism, the DAMTA could be dropped in similar fashion to the plane but from a UH-60 Blackhawk or a CH 47 Chinook helicopter. The helicopter has several advantages over the airplane platform including the accuracy of dropping the platform based on the helicopter's ability to hover and maneuver into more difficult areas (Figure 6.26). "Loss of Combat Power" is also a concern unless multi-tasking equipment and individuals is taken into consideration (e.g., reconnaissance and dropping the DAMTA platform). Table 6.18 represents a list of definitions for each of the considerations.

Table 6.17 - Methods of Sensor Employment

1	2	3	4	5	6	7	8	9	10	11	12
Projected to be used by DAMTA		Maximize Accuracy	Maximize Survivability Minimize Sensor Attrition	Minimize Time to Emplace	Minimize Risk to Force	Minimize Uncertainty	Maximize Availability	Loss of Combat Power		Advantages	Disadvantages
*	By-hand	X	X	X			X	X	X	<ul style="list-style-type: none"> • Accuracy and specific emplacement • Minimize shock of dropping device • Fix any problems on ground 	<ul style="list-style-type: none"> • Risk to Force
*	UH-60 (utility helicopter)	X	X	X	X		X	X	X	<ul style="list-style-type: none"> • Fly a low level pattern • Hover (Accuracy) • Speed (Time) 	<ul style="list-style-type: none"> • Low altitude drop may give position away
*	Plane (example: C130)		X	X	X	X		X	X	<ul style="list-style-type: none"> • Speed (Time) • Risk to Force 	<ul style="list-style-type: none"> • Accuracy • Survivability
*	Glider	X	X	X					X	<ul style="list-style-type: none"> • Fly a low level pattern • Loiter (Hover) 	<ul style="list-style-type: none"> • Detection (low altitude) • Availability
*	Hot Air Balloon	X	X	X						<ul style="list-style-type: none"> • Fly a low level pattern • Loiter (Accuracy) 	<ul style="list-style-type: none"> • Detection • Availability • Speed (Time) • Risk to Force
	Unmanned Ground Vehicle (UGV)	X	X	X		X	X		X	<ul style="list-style-type: none"> • Risk to Force • Accuracy 	<ul style="list-style-type: none"> • Availability • Speed (Time)
	Unmanned Ariel Vehicle (UAV)		X	X		X	X		X	<ul style="list-style-type: none"> • Fly a low level pattern • Hover (Accuracy) 	<ul style="list-style-type: none"> • Availability • Speed (Time)
	Artillery				X	X		X	X	<ul style="list-style-type: none"> • Speed (Time) • Risk to Force 	<ul style="list-style-type: none"> • Tower Attrition • Accuracy
	Mortars				X	X			X	<ul style="list-style-type: none"> • Speed (Time) • Risk to Force 	<ul style="list-style-type: none"> • Tower Attrition • Accuracy
	Missile Package				X	X		X	X	<ul style="list-style-type: none"> • Speed (Time) • Risk to Force 	<ul style="list-style-type: none"> • Tower Attrition • Accuracy
	Grenade Launcher				X			X	X	<ul style="list-style-type: none"> • Speed (Time) • Risk to Force • Some amount of accuracy 	<ul style="list-style-type: none"> • Tower Attrition

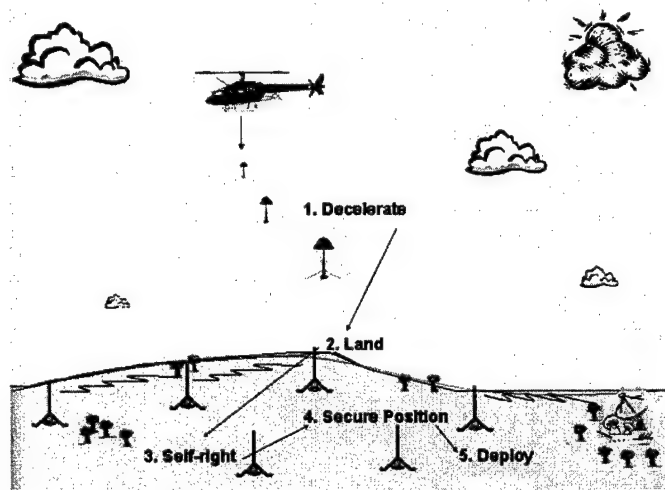


Figure 6.27- Helicopter Employment of DAMTA

Table 6.18 - Sensor Emplacement Consideration Definitions

Sensor Emplacement Considerations	Definition
<i>Accuracy</i>	The quality of approximating a condition or a value. The exactness of placing the platform at a specific location.
<i>Survivability</i>	A property of a system to provide a defined degree of assurance that the system will continue to function during and after a natural or man-made disturbance.
<i>Attrition</i>	The reduction of a system or network of systems after deployment, and during operation.
<i>Time to Emplace</i>	The total duration of time needed to plan, prepare, and configure the DAMTA employment method and then install the platform at a specific location.
<i>Risk to Force</i>	The frequency and severity of placing personnel and/or equipment in a dangerous situation in order to deploy the DAMTA platform.
<i>Uncertainty</i>	Results from unknowns or lack of information. The state of the DAMTA platform depends of the employment means and the certainty of location and functioning status.
<i>Availability</i>	Having the employment means accessible when needed.
<i>Loss of Combat Power</i>	Loss of key pieces of equipment and/or personnel for deployment of the DAMTA platform.

For the question of how many DAMTA platforms will be needed for a specific area of interest is based on the terrain, the operational scenario, and most importantly the range (distance) and resolution of the camera. Lamm, et al. developed a means to generalize the problem by deleting the aspect of terrain and the operational scenario, thus focusing on the detection range of a sensor. Results from the process yielded sensor densities per square area.

6.3 Risks and Vulnerabilities. Imagery is affected by many factors relating to the scenarios and environments we place the capturing device in. We may lack a true understanding of what triggers will affect the reduction or obstruction of imagery and how to mitigate or transfer the risks associated with imagery. Risk is a measure of the probability and severity of adverse effects [Lowrance, 1976]. Developing systems that include the attributes of redundancy, resilience, and robustness will reduce many of the risks associated with imagery. The 3 R's are well known in large-scale systems (i.e., water-resources, space, information and infrastructure systems) and cover specific risk factors associated with imagery. Redundancy refers to the ability of extra components of a system to assume the functions after failure [Haimes et al., 2001]. Resilience is the ability of a system to repair and bounce back following an emergency. Robustness refers to the ability of a system to perform its intended function over the expected useful life in the presence of external stresses or noise.

We do not offer any specific or verified risk analysis (severity or frequency of the scenario) on the environments (Table 6.19) and vulnerabilities (Table 6.20) that affect the DAMTA digital imagery device. The scope of this section is to provide the stakeholders a mapping of the vulnerabilities and environments that DAMTA may have to manage. The mapping may be used as source material to accurately represent the likelihood of each risk scenario (a selected vulnerability in a unique environment) and we may be able to develop components (i.e., instruments, tools or policies) that will reduce the risks of imagery and increase its benefits to users.

It is important to understand the scenarios a system might have to confront and the challenges associated with those scenarios. We chose to offer a methodology that allows key stakeholders to update the thresholds and risk levels of the scenarios. For our analysis natural-language scale levels (high (H), medium (M) and low (L)) are defined for a vulnerability and a corresponding environment (scenario). High (H) equates to 0.80 to 1.00 (80%-100%) probability that the vulnerability will affect imagery operations in that specific environment. Medium (M) and low (L)) represent probabilities of 0.20 to 0.79 and 0.0 to 0.19, respectively. The judgment of the severity of the scenario determines the priority of effort toward further research and testing but this section also represents the methodology of understanding the many factors (Vulnerabilities and Environments) affecting imagery and its benefits to users.

Tables 6.21 and 6.22 map each environment to a specific vulnerability. For example populated areas with building pose a great threat to the DAMTA platform in terms of: 1) people altering, hindering and destroying the device; 2) dropping the device into that specific area (i.e., survivability issues) and 3) communication issues. We have a very good understanding of the vulnerabilities: "Heat", "Cold," "Moderate" and "Shock" by testing for these vulnerabilities. We have brainstormed some of the DAMTA platform vulnerability analysis but there is more analysis and research that needs to be done in this particular area especially in the areas of probability justification and environmental testing.

Table 6.19 - Environmental Factor Descriptions

<i>Environment</i>	<i>Description</i>
PEACE OPERATIONS	Humanitarian or peacekeeping operations with a decreased threat of violence
LOW INTENSITY	Operations in areas where conflict is unlikely and the Operational TEMPO (Rate at which units of the Armed Forces are involved in all military activities) is decreased
POPULATED (DENSE)	Areas with a large number of people
POPULATED (SPARSE)	Areas with a small number of people
HIGH INTENSITY	Operations in areas where conflict is likely and the Operational TEMPO is high
DISASTER RELIEF	Humanitarian environment where the primary purpose is providing aid and support
EMP	Characterized by an electromagnetic pulse which could interfere with electronic performance
NIGHT	Environment where darkness prevails
DAY	Environment where daylight prevails
CONSTANT OVERCAST	Environment dominated by cloud cover and limited air visibility
WET (RAINY)	Wet climate characterized by rain and humidity
DRY (DESERT)	Arid climate with little rain and typically very hot
TROPICAL	Wet, hot environment with predictable rain showers and high humidity and dense vegetation
NORMAL TEMP	Seasonal environment with predictable weather patterns
COLD	Environment characterized by temperatures below freezing
RURAL	Sparsely populated area with little infrastructure or dwellings
TOWN CITY	Densely populated area with increased infrastructures, commerce, and dwellings
FLAT	Area characterized by level terrain
HILLY	Area characterized by uneven terrain changing in altitude
MOUNTAINESS	Area characterized by mountainess terrain with high altitudes and few flat areas
TREES/DENSE	Area characterized by thick vegetation/trees

Table 6.20 - Vulnerability Descriptions

<i>Vulnerabilities</i>	<i>Description</i>
HEAT	Areas posing a threat of high temperatures in excess of 90 degrees.
COLD	Areas posing a threat of low temperatures in areas below freezing temperature.
PROJECTILES	Structurally threatening objects natural or manmade that can potentially damage the DAMTA platform
HOSTILE ENVIRONMENT	Hazardous or unfriendly environment characterized by violence or the intent to do harm
BUILDINGS	Structures interfering with the positioning or the transmission of the DAMTA platform
WATER (RAIN)	Natural Hazard threatening the electrical component of the cameras
PEOPLE	Humans that pose a threat to the platform through destruction, vandalism, or theft
ANIMALS	Creatures posing a threat of destroying or harming the platform
UNEVEN TERRAIN	Any terrain not on a flat level impeding the landing and self-righting portion of the employment
ELECTROMAGNETIC INTERFERENCE	Interference that inhibits the collection and transmission of weather information
SUN (DIRECTLY AT CAMERA)	Sunlight inhibiting the ability of the camera to transmit quality imagery
HEAVY FOG	Fog dense enough to prevent beneficial imagery and weather data from being sent
LASERS (DEW)	Precipitation limiting the capability of the cameras to function properly
WIND (SAND STORM) (HURRICANE/TORNADOS)	Intense winds making the parachuting and landing stages difficult. Additionally, once on the ground the wind can pose a significant threat to the position and stability of the platform.
SNOW	Snow that can cover the camera or limit the ability of the platform to provide the necessary information.

Table 6.21 - Environmental Factor Descriptions

	PEACE OPERATIONS	LOW INTENSITY	POPULATED (DENSE)	(SPARSE)	HIGH INTENSITY	DISASTER RELIEF	EMP	NIGHT	DAY
ANIMALS									
BUILDINGS									
COLD									
ELECTROMAGNETIC INTERFERENCE									
HEAT									
HEAVY FOG									
HOSTILE ENVIRONMENT									
LASERS (DEW)									
PEOPLE									
PROJECTILES									
SNOW									
SUN (DIRECTLY AT CAMERA)									
UNEVEN TERRAIN									
WATER (RAIN)									
WIND (SAND STORM) (HURRICANE/TORNADOS)									

Table 6.22 - Environmental Factor Descriptions (Continued)

	WET (RAINY)	DRY (DESERT)	TROPICAL	NORMAL TEMP	COLD	RURAL	TOWN CITY	FLAT	HILLY
ANIMALS									
BUILDINGS									
COLD									
ELECTROMAGNETIC INTERFERENCE									
HEAT									
HEAVY FOG									
HOSTILE ENVIRONMENT									
LASERS (DEW)									
PEOPLE									
PROJECTILES									
SNOW									
SUN (DIRECTLY AT CAMERA)									
UNEVEN TERRAIN									
WATER (RAIN)									
WIND (SAND STORM) (HURRICANE/TORNADOS)									

Section 7 – Hardware Selection

This section provides an in-depth look at the methodology undertaken to select the best off-the-shelf imagery sensor (camera) to be used with the DAMTA platform. While Sections 5 and 6 outlined the analysis of benefits that would accrue from the use of an imagery enhanced DAMTA, this section studies the practical issue of selecting the right imagery sensor.

7.1 Alternatives Generation. Having established the benefits from imagery, we pursued the generation of alternative cameras to be considered for integration with the platform. This section recaps the process used to generate a feasible list of cameras to purchase for initial testing.

7.1.1 Initial Development of Alternatives. The initial list of cameras to test was developed sequentially through two processes: 1) The Initial Market Search and 2) The Continuing Market Search. The first involved an initial development of camera criteria followed by a concerted search for available off-the-shelf alternatives. This study lasted 3 weeks and was conducted in July 2002. The second process extended from August 2002 through December 2002 and provided an open-ended opportunity to consider new cameras and reject infeasible cameras as our research proceeded and our criteria for selection were refined.

7.1.1.1 Initial Market Search. In July 2002, Cadet Chris Green traveled to ARL-WSMR in New Mexico for an intensive 3-week study to initiate our search for feasible cameras for testing. This trip fulfilled an academic opportunity for him under the USMA Academic Individual Advanced Development (AIAD) program. This program allows cadets to travel worldwide to pursue academic internships during the summer. Cadet Green had been previously identified to assist the DAMTA team in the fall of 2002, so his selection to go to ARL-WSMR was done with the expectation that he would be able to initiate the search for cameras.

Cadet Green initially worked with ARL-WSMR colleagues to establish a list of soft criteria for the imagery sensors that would be appropriate for the DAMTA. Having established this list, Cadet Green then conducted a market search via the Internet and telephone to generate an initial list of cameras. The specifications for these cameras were then compared against the initial list of criteria as an initial feasibility screen that is shown at Table 7.1.

In Table 7.1 the initial list of cameras is listed down the left side of the table. Across the top the camera criteria are listed. Intersecting rows and columns establish whether or not the camera meets that

particular criterion. If the criterion is met, the box is shaded green and labeled as "Yes." If the criterion is not met, the box is shaded yellow and labeled as "No." If conformance to the criteria could not be determined, the box was shaded orange and labeled "?". Any camera meeting all the criteria was deemed as a feasible candidate for testing as represented by green shading in the left column.

The feasibility criteria are explained below. These criteria were established in conjunction with researchers at ARL-WSMR who were involved with the SBIR Phase II contract specifics and who were in a good position to define specifications for the cameras.

Feasibility Criteria:

- **Image Capture** – The camera had to be digital capture.
- **Dimensions** – 7 x 10 x 14 centimeters was established as the maximum dimensions for the camera. These physical dimensions captured the fact that the DAMTA platform itself was constrained by size. At the time this criteria was established, a preliminary design for the DAMTA was complete and a very simple prototype had been constructed. ATI complete the initial valid prototype in November of 2002.
- **Weight** – 250 grams was established as the maximum camera weight. This criterion reflected the need to minimize the total weight of the DAMTA. As it was anticipated that the cameras would need to be high on the DAMTA platform, minimizing this weight also helped to keep the platform center of gravity low to preclude tipping.
- **Resolution** – 300 TV lines was established as the minimum resolution to ensure that sky and horizon images provided sufficient optical clarity to discern various atmospheric phenomena.
- **Price** - \$250 was established as the maximum cost per camera. At this point, no specifications had been provided or expectations set regarding the number of cameras per platform.
- **Power Requirement** – 9VDC was established as a threshold for power requirements. At this point, no significant power studies had been conducted and the power requirements for the cameras were based on the anticipated need to keep requirements to a minimum since the DAMTA would operate for 30 days on a single battery. Most cameras, as it turned out, accept 9 – 14 VDC so this was a good initial target.
- **Operating Temperature** – 5° C to 40° C was established as the minimum and maximum operating temperatures. The lower threshold was eventually lowered to reflect the need to employ the DAMTA in widely varying climatic conditions. The cameras were later tested at operating temperatures below this range to ensure they met the criterion.
- **Illumination** – The initial expectation is that the cameras would not be required to capture images at night. However, the lower the lux rating for each camera, the better it will operate during the hours of dawn and dusk. Thus 3 lux was established as the cutoff.

- Usable off-the-shelf – This criteria required that the camera have some type of housing, which could be directly mounted to the DAMTA. Examples of cameras not meeting this criteria were “board cameras” which are essentially small pinhole cameras soldered to a circuit board, where the board has no housing.
- Weatherability – This somewhat subjective criterion required that cameras have sufficient protection from environmental elements (precipitation primarily) to keep them from malfunctioning during a 30-day deployment.
- Field of View – Given that cameras would probably be fixed (vice panning or rotating cameras), this criterion provided that each camera should have a horizontal field of view greater than 55 degrees to ensure that two or three cameras could cover a representative part of the horizon.

Cadet Green presented his findings to the group’s senior researcher in August 2002. His research was reviewed and the feasible cameras from his study were established as the initial alternatives to consider purchasing for testing and evaluation.

Table 7.1 - Initial Feasibility Screen

Criteria		Image Capture (Digital)	Dimensions (< 7x10x14cm)	Weight (< 250g)	Resolution (Horiz > 300 TV)	Price (< \$250)	Power Rqmt (< 9V DC)	Operating Temp (>5°C < 40°C)	Illumination (< 3 lux)	Usable off the Shelf	Weatherability (Included)	Field of View (> 55°)	Feasible?
Camera Type													
AYesis 2100		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AYesis 2120		Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Visiontech VC33WP		Yes	Yes	Yes	Yes	Yes	Yes	Yes?	Yes	Yes	Yes	Yes	Yes
Visiontech VC33C/CS		Yes	Yes	Yes	Yes	Yes	Yes	Yes?	Yes	Yes	Yes	Yes	Yes
EM200-L25		Yes	Yes	?	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
EMH200-L25		Yes	Yes	?	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
Panasonic GP-CYes161/5		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Panasonic GP-CYes171		Yes	Yes	?	Yes	?	Yes	Yes	Yes	No	No	Yes	No
YC-100		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes CAM 2		Yes	Yes	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes CAM 2 WideEye		Yes	Yes	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes CAM 2 InstantON		Yes	Yes	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes10 Nightwatch		Yes	Yes	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hi Res Bullet (B/W)		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hi Res Bullet (Color)		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GE MicroCam		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
GE ColorCam		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Yes Possesses Attribute
 No Does Not Possess Attribute
 ? Unknown
 Yes? Testing Required

7.1.1.2 Continuing Market Search. Technology in the area of imagery is quickly changing, and new cameras are continually being marketed. Similarly, cameras are being pulled from the market as newer ones replace them. The availability of new CCD chip sets with higher resolution and better optical qualities tends to drive these market changes. As a result, the team recognized the need to conduct continual surveys of the market throughout the research period to ensure that we considered the newest and best off-the-shelf products available. Cadet Green's initial list of feasible cameras was modified to account for these market changes and to account for input from the senior researcher. His list was paired down and added-to resulting in the list in Table 7.2. Column 4 in the table is entitled "Final Spec Review/Purchase." The green shaded blocks indicate cameras that passed the senior researchers review, were available on the market, and were purchased for testing.

Table 7.2 – Final Camera Feasibility Matrix

Camera Type	Camera Selection Phase	Initial Spec Review	Final Spec Review / Purchase	Cold Test	Temperature Test	Hot Test	Shock Test	Overall Feasibility
Axis 2100	Original	X	O					Fail
Axis 2120	Original	O						Fail
Visiontech VC33WP	Original	X	O					Fail
Visiontech VC33C/CS	Original	X	O					Fail
EM200-L25	Original	X	O					Fail
EMH200-L25	Original	X	O					Fail
Panasonic GP-CX161/53	Original	O						Fail
Panasonic GP-CX171	Original	O						Fail
YC-100	Original	X	X	O	X	X	X	Fail
X CAM 2	Original	X	O					Fail
X CAM 2 WideEye	Original	X	O					Fail
X CAM 2 InstantON	Original	X	O					Fail
X10 Nightwatch	Original	X	O					Fail
Hi Res Bullet (B/W)	Original	X	X	O	X	X	X	Fail
Color Bullet CCD	Original	X	X	X	X	X	X	Pass
GE MicroCam	Original	X	O					Fail
GE ColorCam	Original	X	O					Fail
WATEC LCL 211	Added		X	X	X	X	X	Pass
WATEC LCL 217	Added		X	X	X	X	X	Pass
WATEC Board	Added		X	X	X	X	X	Pass
Marshall Color Bullet	Added		X	O	X	X	O	Fail
Micro Video MVC3000H	Added		X	X	X	X	X	Pass
Micro Video MV 2300	Added		X	X	X	X	X	Pass
Micro Video MVC 3200C Pinhole	Added		X	X	X	X	X	Pass

X Passes Testing
O Does Not Pass Test

7.1.2 Purchasing. Funds for the project were transferred into our account at USMA in September. Upon receipt of funds, and final review of feasible cameras, the team began making purchases. The major purchases through the end of 2002 included the following items:

- Cameras -- The feasible cameras were purchased through several different companies
- Tools - A number of tools were required to complete mechanical and electrical work on the cameras in preparation for testing
- Network Camera Servers -- Two Axis Network Camera Servers were purchased to enable real time monitoring of remotely placed cameras during testing. These were used primarily during the Cold Weather tests in Alaska to monitor camera status through streaming video to our desktops in New York.
- Video Equipment -- A video switcher was purchased to allow quick monitoring of multiple cameras during testing. A frame grabber was purchased to allow individual video pictures to be saved to a laptop computer for analysis. A 12 VDC power supply was purchased to use during cold and hot weather testing in Alaska and Panama. Cables, connectors, small tripods and miscellaneous items rounded out the list of necessary equipment to set up and perform the tests.

7.2 Testing. Five phases of testing were conducted to assist in the final selection of cameras. Once the feasible cameras were purchased, a home base test was conducted to ensure that cameras met basic requirements for integration with the DAMTA and to design appropriate test stands for environmental testing. A cold weather test was then conducted at Fort Greely, Alaska. This was followed by a hot/tropical test in Gamboa, Panama. Temperate climate testing was conducted at West Point, NY. Finally, a shock test was conducted to ensure the cameras could withstand the initial shock of the DAMTA landing after descent from the airborne platform.

7.2.1 Home Base Test and Preparation. Three basic types of cameras were purchased: bullet cameras, board cameras and miniature video cameras. The bullet cameras are completely weatherproof. They normally measure between 2.5 to 3.5 inches in length, and .75 to 1.0 inches in diameter. They are shaped like a small cylinder. Camera 4 in Figure 7.8 (the Color Bullet (Long)) is an example of a bullet camera. Board cameras are typically small pinhole video cameras soldered right onto a small circuit board. They use pinhole technology and have no lenses. The team tested board cameras that were housed, and those that had no housing. Camera 3 in Figure 7.8, the MVC 3200 C is an example of a board camera with an integral housing. The third type of camera tested was essentially a standard box-shaped video camera in a very small housing. These typically measured 3.5 inches long by 1.5 inches high by 1.5 inches wide and had detachable lenses. Camera 6 in Figure 7.8, the Watec LCL 217, is an example of this type of camera.

Each of the eight feasible cameras was tested at USMA to ensure that the team had all the proper equipment to operate and evaluate each camera. This initial home base testing and preparation included the following:

- All cameras were powered by a 12VDC power source. Connectors were purchased and fitted to each camera to provide power from a single 12VDC power supply.
- Each camera was successively hooked via standard coax cable to a video monitor to ensure proper operation.
- Two wooden test stands were built. Each stand was fitted with four small tripods. Cameras were affixed to the tripods. A small cardboard housing was fabricated to protect the board camera from the elements.
- The AXIS network camera server was tested locally to ensure that images could be transferred remotely via the network from the cameras to a computer monitor.
- Coax cable sets were measured, cut and fitted with BNC connectors to reduce the labor required at test sites. Cable sets were approximately 75 - 90 feet long.
- Power cable sets were measured, cut and fitted with connectors to reduce the labor required at test sites. Cable sets were approximately 75 - 90 feet long.
- A list of required tools and equipment was developed to ensure that all equipment required for each test was on the packing list.

7.2.2 Cold Weather Test – Fort Greely, AK – 21 Jan – 25 Feb 03. Cold climate testing was conducted from 21 Jan – 25 Feb 2003 at the Cold Regions Test Center (CRTC) at Fort Greely, Alaska. The purpose of this test was to determine camera effectiveness and operational capability in a cold climate. This represented the cold weather extreme for DAMTA deployment.

7.2.2.1 Preparation. The preparation for the Cold Weather Test in Alaska began in the early parts of October 2002. LTC Buckingham, along with the rest of the DAMTA team, conceived the notion of sending cameras to Alaska to test their durability in the cold temperatures. Over the course of the next two months, a proposal and test plan were written as a deal with the CRTC at Fort Greely, Alaska was brokered.

The final eight cameras the team decided to test were:

- Camera 1 - Color Bullet (Long) North American Video
- Camera 2 - Color Bullet (Short) Marshall Electronics

- Camera 3 - B/W Bullet
- Camera 4 - I/R Bullet
- Camera 5 - WATEC (LCL217)
- Camera 6 - WATEC (LCL211)
- Camera 7 - YC-100
- Camera 8 - Board Camera

The next task beginning in early January, two weeks prior to the test, was to fashion the equipment so it was in a condition to test. As a caveat to ensuring the equipment was ready, the team had to prep some secondary equipment that would be required for the test in Alaska. Items on the secondary list included: coax cable, power cords, a switcher, network camera sensors, and camera mounts.

Since the team intended to test eight of the cameras, equipment had to be furnished to support all eight individually and collectively. Coax and power cables were fashioned in two groups of four. One group was cut and fitted to the specific needs of the cameras with a length of 90 feet. The other set of four cables were also specific to each camera but only had a length of 75 feet. Each cable was marked with either one or two pieces of colored tape to delineate the camera to which it corresponded. Figure 7.1 shows the construction of the cables.

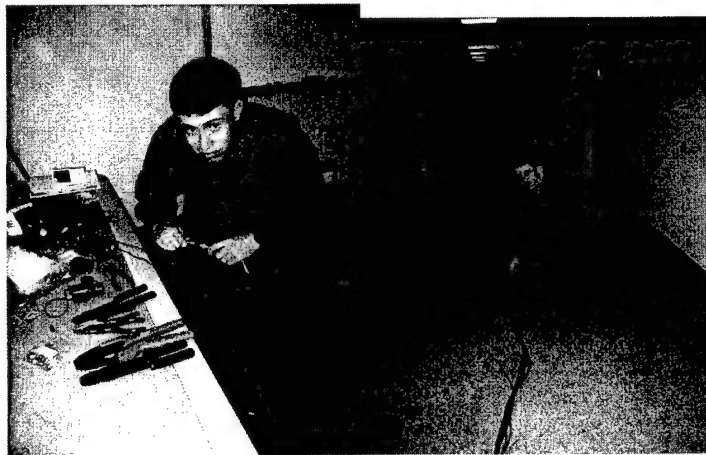


Figure 7.1 - Cadet Green Preparing Cables for Cold Weather Test

Once the cable was constructed, there were only two tasks needing to be accomplished before the team was ready to test the equipment. First, a camera mount was created to which all eight cameras could be attached for the test. The final problem that was solved prior to testing was weatherproofing for the board camera. The solution was to surround the board with cardboard to protect it from the elements and then place a layer of duct tape over the top to keep out moisture.

Once all the equipment was functional and had been tested, all equipment needed for the test was packed in two large trunks for transport to Fairbanks, Alaska along with LTC Buckingham and CDT Green who would test the equipment in January and February.

7.2.2.2 Cold Chamber Test. The cold chamber is a tool that the CRTC uses to evaluate the performance of objects in extremely cold conditions. The team used the cold chamber to evaluate the performance of the eight individual cameras in temperatures down to and including fifty degrees below zero.

Setup

The first phase of the cold chamber test began on the morning of 21 January. Upon arrival at the main CRTC Building on post, LTC Buckingham and Cadet Green met Mike Kingston, the team's liaison to the center. Mr. Kingston along with associate Dan Lucas were able to help the team set up the equipment inside the cold chamber for testing the next day.

The test setup consisted of the eight cameras mounted on two test stands sitting on a table inside the cold chamber. The cameras were aimed at the far wall of the chamber where colorful posters were mounted to provide an optical target against which to compare images as the temperatures dropped. One major problem the team ran into during this particular part of the setup was the artificial lighting inside the chamber. The lighting and the metal walls proved to be a problem because of the colors emitted as well as the reflection from the metal walls. The solution to the problem was to limit the lighting to one source that bounced light off the back wall to reduce the reflection, glare, and various colors. Figure 7.2 shows LTC Buckingham and CDT Green working together to set up the cameras inside the cold chamber.



Figure 7.2 – LTC Buckingham and Cadet Green in the Cold Chamber

The cameras were connected by their associated cables which ran to the outside of the chamber and were connected with a switcher box that allowed the team to view the image from any one camera on a monitor. The switcher also allowed the team to capture images of the cameras at various temperatures through use of a laptop computer. The computer setup outside the cold chamber is shown in Figure 7.3.

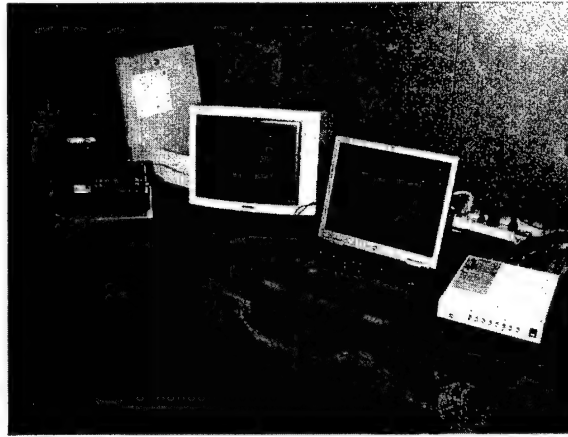


Figure 7.3 – Data Collection Equipment Outside the Cold Chamber

Once the setup was complete, the team initiated the cooling process of the chamber. The temperature was set to 15 degrees Fahrenheit and the cameras were left inside overnight in order to acclimatize them to the cold environment. After they were cold soaked through the night, the cameras would be ready for testing in the morning.

Testing

The Cold Chamber Test took place on 22 January. Following the cold soak on the previous night, the cameras were acclimated to the environment and the temperature in the chamber could be dropped to begin the test. The team incrementally dropped the temperature by 10 degrees at a time and allowed the chamber to cool. This process took anywhere between 10-15 minutes depending on how cold the thermostat was set. Once the chamber reached the desired temperature, the team waited an additional 15 minutes to allow the cameras to cool to the temperature of the chamber. Once the allotted time had elapsed, the team entered the chamber to take an exact temperature reading from the surface of the cameras. This temperature was recorded by one of the team members as the other captured an image of the camera at the specific temperature. Figure 7.4 shows the process of capturing data at a given temperature. LTC Buckingham is reading the surface temperature of the cameras (left) as Cadet Green captures the images on the laptop for future use (right).



Figure 7.4 – LTC Buckingham and Cadet Green Collecting Data During Cold Chamber Test

The chamber was dropped from fifteen degrees to 0, -10, -20, -30, -40, and -50 on each successive temperature decrease. The actual surface temperatures of the cameras read 3, -9, -19, -31, -38, -48, respectively. Significant impacts were noted on the Color Bullet (Short) and the YC-100. During the test the short color bullet began to decrease in brightness starting when the temperature of the surface of the camera reached -9 degrees Fahrenheit. Eventually, the image was so dark that nothing could be seen by the time the temperature reached -31 degrees Fahrenheit. The YC-100 experienced a completely different problem toward the middle of the test. At this time, the YC-100 powered down and shut off at -31 degrees Fahrenheit. The cameras were brought outside the chamber, warmed, and inserted back into the chamber at -38 degrees Fahrenheit. The power came back on but soon turned off again as the camera began to cool. The YC-100 also experienced lens problems and had to share a lens with the WATEC (LCL217).

Once the test was complete, the team disassembled the equipment and packed it back in the trunks. The equipment needed to be ready to move to the long-term test facility at Bolio Lake the next day.

7.2.2.3 Bolio Lake Test.

Setup

The installation of the camera equipment at the Bolio Lake Test Facility was reserved for 23 January. At this time, the team transported the equipment from the Fort Greely CRTC site to the Bolio Lake CRTC Site. Here, the team linked up with Mr. Kingston to set up the equipment for the 30-day test.

Once at the site, the team began work re-assembling the camera equipment to display it outside. The cameras were mounted on their platforms and brought outside where the temperature was -24°F . The coax and power cables ran from a secure box inside through a pipe to the outside where they were affixed to the cameras. The initial setup of the cameras is depicted in Figure 7.5.

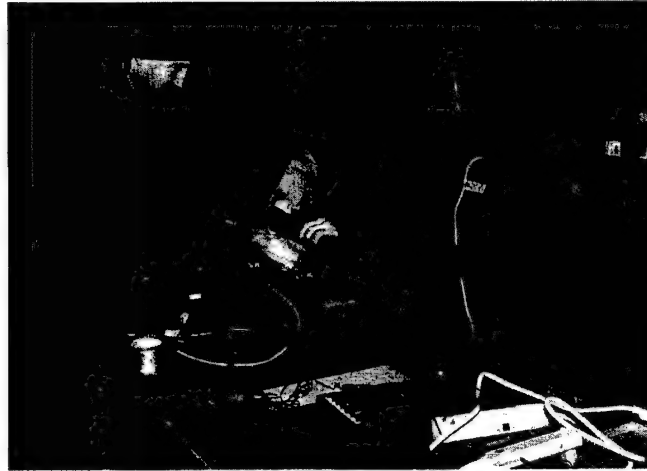


Figure 7.5 – Preparations for 30-Day Test at Bolio Lake

The cameras were set up outside one of the testing facilities looking out toward the lake, mountains and horizon. The two individual mounts were clamped to two wooden stands frozen to the ground. See Figure 7.6 below.



Figure 7.6 – Test Stands at Bolio Lake

Network Connection

Once the hardware was setup outside the facility one matter was left to be resolved. The network camera servers had to be installed in order for the team to see the images in Alaska from New York. This task proved harder than originally thought. Although the instructions were simple, a breakdown in a

network hub prohibited the team from getting the hardware to work properly the first day. The problem was finally resolved on 27 January with the return of a network specialist to the Bolio Facility.

Testing

The cameras were left outside at the Bolio Lake Facility for a period of approximately 30 Days (23 January – 25 February). During this time, the design team back at West Point had access to the images of the cameras in Alaska via Internet. The team captured daily images to use in the analysis of the data. Figure 7.7 shows an example of a daily image captured from the first four cameras on 4 February 2003.

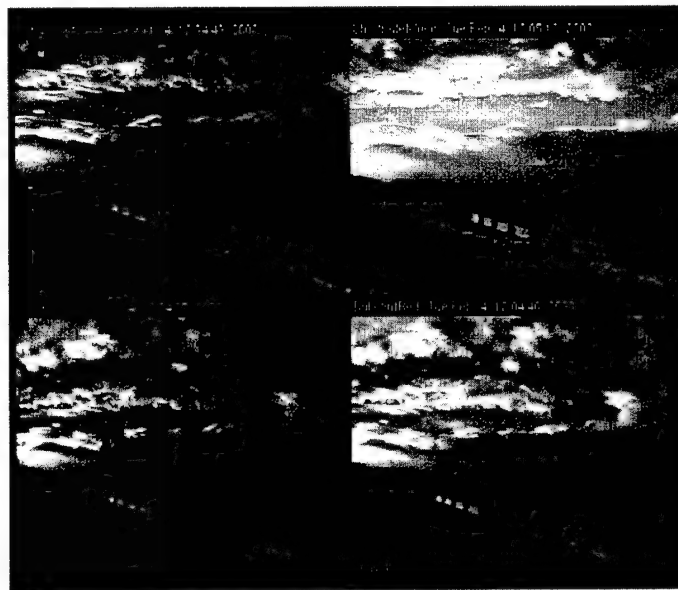


Figure 7.7 – Quad Image of Live-Feed Video from Test Cameras in Alaska

The administrative liaison, Mike Kingston, took care of minor camera maintenance during the 30-day test.

7.2.2.4 Retrieval. From 26 - 28 February, LTC Buckingham traveled to Fort Greely to retrieve the test equipment. By this time, three additional cameras had been researched and purchased for testing. These cameras were:

- Camera 1 – Micro Video MVC 3000 H
- Camera 2 – Micro Video MV 2300
- Camera 3 – Micro Video MVC 3200 C Color Pinhole Camera

These three new cameras were tested in the cold chamber and all three performed flawlessly.

7.2.2.5 Analysis of Data. On a daily basis, images were viewed and/or captured from each of the cameras. At the end of the test, CRTC furnished LTC Buckingham with a computer printout of the climatic conditions for the Bolio facility during the evaluation period. The team utilized this information along with the images captured during the test period and the data garnered from the cold chamber test to determine how well the cameras performed in cold weather. This information was used both to perform an ongoing feasibility determination for each camera, and to provide data from which to select the optimal camera for the DAMTA application.

The data analysis yielded the following conclusions:

- The black and white cameras should be dropped from further consideration. Specifically, the following two cameras were dropped: Camera 3 - B/W Bullet and Camera 4 - I/R Bullet. This was not a cold environment decision. It was an operational decision made in the cold environment, which is applicable to every environment. Essentially, black and white cameras provide excellent resolution, but the grayscale is ineffective in differentiating between important environmental effects in the atmosphere. Color cameras enable the user to immediately identify white clouds from blue sky. Figure 7.7 demonstrates this. The two pictures in the lower part of the quad image are black and white. It is very hard to discern from these images exactly which part of the sky is clear and which part clouds obscure. The upper two images make this determination very simple.
- The YC-100 camera lost power at approximately -30 degrees F and would not function at colder temperatures. Although this camera functioned properly once the temperature was raised, the team determined it should be dropped from the list for failing to operate.
- The Color Bullet (Short) camera made by Marshall, began to lose brightness at -9 degrees F. As the temperature dropped further, the picture became completely dark. The team did not consider this a feasibility failure.

7.2.2.6 Cold Test Conclusions. The Cold Test was a very beneficial part of the DAMTA project. It enabled the design team to eliminate three cameras and also to confirm the cold weather performance of five cameras. It provided clear evidence of the need for color cameras for the DAMTA application.

7.2.3 Hot/Tropical Test – Panama – 17-21 March 2003. Hot/tropical climate testing was conducted from 17 -21 March 2003 in Gamboa, Panama. The purpose of this test was to determine camera effectiveness and operational capability in a hot/tropical climate. This represented the hot weather extreme for DAMTA deployment.

7.2.3.1 Preparation. The preparation for the hot/tropical climate test in Panama began in early October 2002. LTC Buckingham and the DAMTA team decided to take candidate cameras to the Army's hot/tropical testing site to test their effectiveness and operational capability in a hot and tropical climate. The hot/tropical test site is operated under the auspices of the Yuma Proving Grounds in Arizona. Initial coordination revealed that the primary hot weather test site was operated in Panama, but that plans were being made to set up a site in either Hawaii or Australia. Over the course of the next four months, a proposal and test plan were written and approved for testing in Panama. Since the U.S. Military left Panama on 31 December 1999, control and operation of the hot test site was contracted with a company in Texas that sub-contracts with a Panamanian contractor to run the site. All coordination was made directly with Yuma Proving Grounds.

The initial task was to determine the eight cameras that would be transported to Panama to be tested. During the cold weather test, certain cameras were deemed infeasible, and several other cameras were researched and purchased for continued testing. The final eight cameras the team decided to test are listed below and shown in Figure 7.8.

- Camera 1 – Micro Video MVC 3000 H
- Camera 2 – Micro Video MV 2300
- Camera 3 – Micro Video MVC 3200 C Color Pinhole Camera
- Camera 4 - Color Bullet Long – (North American Video)
- Camera 5 - WATEC (LCL211)
- Camera 6 - WATEC (LCL217)
- Camera 7 – WATEC Board Camera
- Camera 8 – Color Bullet Short (Marshall Electronics)

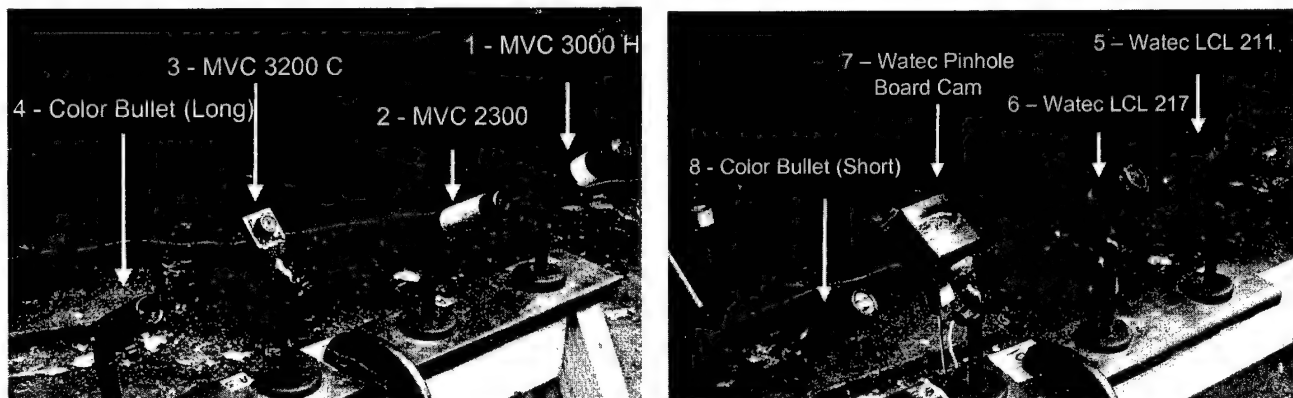


Figure 7.8 – The eight cameras tested in Panama at the Hot/Tropical Test Site

The test equipment package used in Alaska for cold weather testing was essentially reassembled for testing in Panama. In accordance with the hot/tropical test plan, the intent was to set up the cameras at the test site in Panama and leave them in place for 30 days. During that time, a network camera server attached to the cameras would be queried through a modem and phone line to transmit current images from Panama to the research team at the U.S. Military Academy at West Point, NY. This would enable real-time analysis of hot/tropical weather affects on the camera systems.

Once all the equipment was functional and had been tested, all equipment needed for the test was packed into two large trunks to transport the test material to Panama.

A week prior to the test, the hot test point of contact at YPG informed us that they would be unable to provide telephone lines at the test site for at least 30 days. A decision was made to continue plans to conduct the test with a modified test plan. Instead of leaving the equipment in Panama, the complete test would be conducted in 4 days. This would provide an opportunity to ensure that the cameras functioned with the heat and UV loading, but it precluded the opportunity for a full 30-day test in this environment.

7.2.3.2 Hot/Tropical Test. Two sites are available for hot/tropical testing in Panama. The first is at the location of Fort Sherman, Panama, which was vacated by military personnel in 1999. The second is in the small town of Gamboa, about halfway between Panama City and Colon, Panama. Fort Sherman was ruled out because the Panamanian contractor did not have access to power at that site. Gamboa was selected because of the availability of power, even though it had no telephone hookups as mentioned above.

Set-Up

LTC Buckingham arrived in Panama on Monday, 17 March, 2003. The following morning he was taken to the test site at Gamboa. A private company that owns a tourist resort and conducts cable car tours of the jungle in the area owns the test site. The basic test site is shown in Figure 7.9.

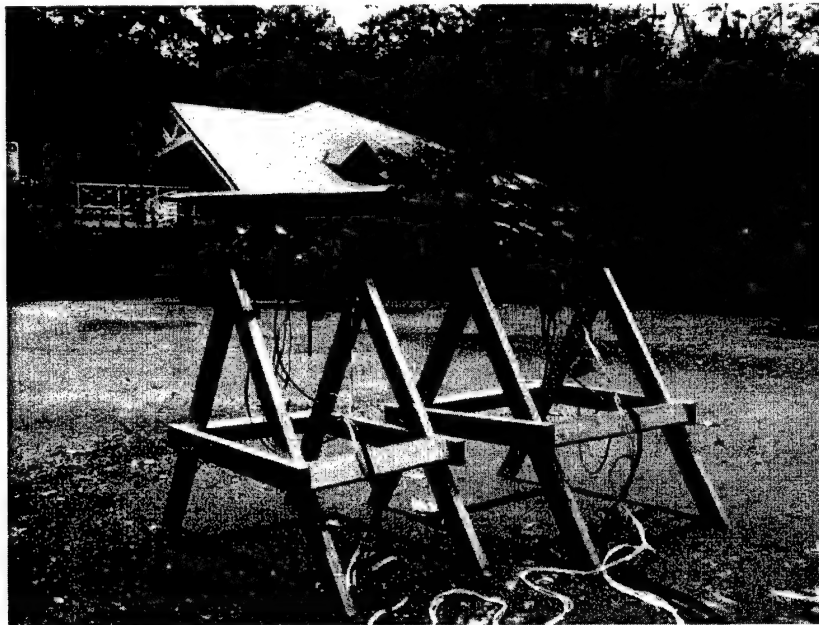


Figure 7.9 – Hot/Tropical Test Site in Gamboa, Panama

Since the test site was privately owned, the equipment had to be set up and removed each day as it was not in a secure area. This further detracted from the effectiveness of the test since the equipment would not be subjected to uninterrupted exposure to the tropical environment for the full four days. The monitoring equipment was set up outside and connected to power by an extension cord hooked to the cable car building. The set-up is depicted in Figure 7.3.

The camera test stands were positioned next to each other at the test site with a field of view encompassing the treetops and the sky. The initial location was about 60 feet down the road from the data logging equipment as shown in Figure 7.4. The final location was adjacent to the data logging equipment to ensure the security of the equipment in a public environment as shown in Figure 7.5.



Figure 7.10 – Monitoring Equipment at Test Site in Gamboa, Panama

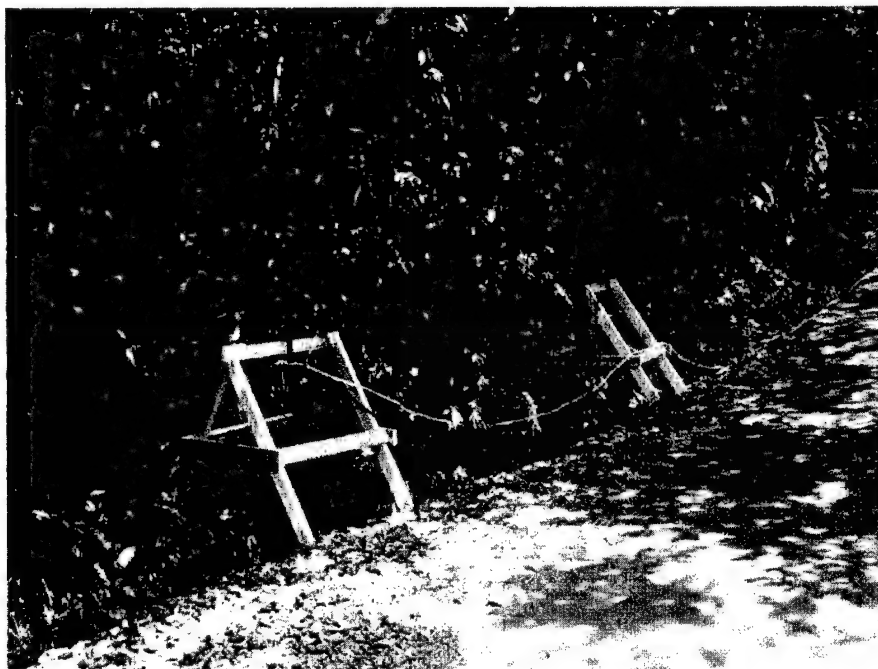


Figure 7.11 - Cameras on test stands at initial location in Gamboa

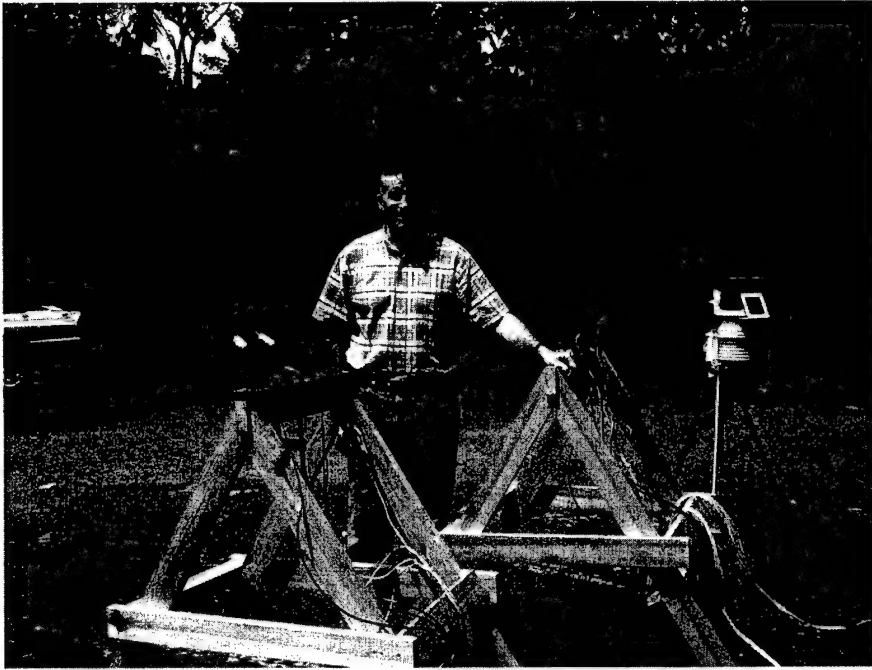


Figure 7.12 - Cameras on test stands at final location in Gamboa

On 18, 19 and 21 March, the equipment was set up and removed each day at the Gamboa test site. On each test day, the cameras were subjected to the tropical environment for approximately three hours from 1100 – 1400. This period represented the extreme in temperature, humidity and solar radiation during the test days. A portable meteorological station was set up on the site to capture meteorological data during the test. This equipment provided the following climatic data for the test:

Table 7.3 – Sample Climate Data

Test Date	Hi Temp (F)	Low Temp (F)	Humidity (%)	Heat Index (F)
3/18/03	91.0	84.7	64 - 71	92.8 – 98.7
3/19/03	84.4	83.7	69 - 76	92.6 – 99.1
3/21/03	93.9	86.6	51 – 68	95.2 – 102.3

7.2.3.3 Analysis of Data. Selected images from the test are shown in Figure 7.6. These photos represent snapshots of video images collected from the cameras during the test. All eight cameras performed satisfactorily throughout the test period in the hot/tropical climate. None of the cameras exhibited any permanent degradation of images throughout the test that would eliminate them from further consideration as an imagery sensor for the DAMTA. However, some of the cameras that were tested had been previously tested in Alaska at the Cold Regions Test Center and retained some long-term optical damage, which was replicated during the hot test. In addition, one of the cameras exhibited some negative optical traits as described below.

- Watec LCL 211 – This camera exhibited some specific optical degradation when the sun was in the field of view of the camera. A vertical band or streak of light tended to dominate the image and detract significantly from image quality. This is clear from the image from camera 5 in Figure 7.13.



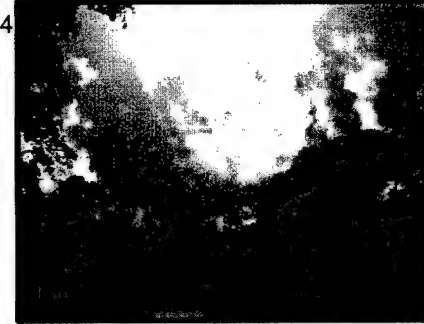
1 - MVC 3000 – 31 deg C, 70% H



2 - MVC 2300 – 29 deg C, 71% H



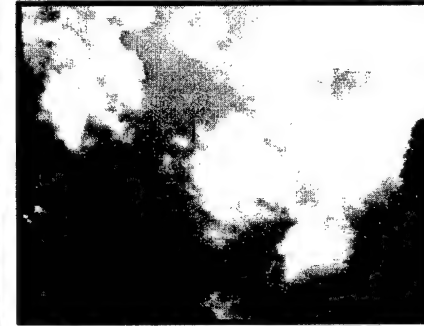
5 - Watec LCL 211 – 31 deg C, 70% H



6 - Watec LCL 217 – 29 deg C, 76% H



7 - Watec Board Cam – 29 deg C, 76% H



8 - Color Bullet (Short) – 29 deg C, 75% H

Figure 7.13 – Individual Snapshots from Each of 8 Cameras in Hot Test

7.2.3.4 Hot/Tropical Test Conclusions. The following conclusions were reached regarding subjection of the eight cameras to the hot/tropical environment in Panama:

1. All of the cameras perform satisfactorily with essentially no degradation to image quality when subjected to average tropical conditions. These conditions included heat index values over 100 degrees F, humidity in excess of 70% and 3 hours worth of UV loading during the extreme heat of the day.
2. One camera, the Watec LCL 211, was particularly sensitive to direct sunlight, which created a vertical streak in the image that degraded image quality.
3. The test was inconclusive as to effects on the cameras for a full 30-day period since the test site did not support continuous deployment of the cameras for that period.
4. Additional testing in a hot/tropical environment should include:
 - a. Testing during the rainy season.
 - b. Exposure for a full-uninterrupted 30-day period

7.2.4 Temperate Weather Test. The temperate weather test was performed at West Point, NY. This test required no travel and was well resourced. The test was performed during the period 26 Mar – 15 Apr 03. The purpose of the test was to expose the cameras to a temperate environment and to investigate the effects of precipitation (primarily rain) on the performance of the cameras.

7.2.4.1 Preparation. Very little preparation was required for this test. None of the cameras exposed to hot/tropical conditions were eliminated, thus the same eight cameras were subjected to the temperate climate test as follows:

- Camera 1 – Micro Video MVC 3000 H
- Camera 2 – Micro Video MV 2300
- Camera 3 – Micro Video MVC 3200 C Color Pinhole Camera
- Camera 4 - Color Bullet Long – (North American Video)
- Camera 5 - WATEC (LCL211)
- Camera 6 - WATEC (LCL217)
- Camera 7 – WATEC Board Camera
- Camera 8 – Color Bullet Short (Marshall Electronics)

The cameras were positioned on the top of Mahan Hall, Building 752 at West Point, NY. Figure 7.10 shows Cadet Green with the eight cameras on the roof. Coax cable was run to the 4th floor of Mahan

Hall and directly into LTC Buckingham's office. 12VDC power cables were run from LTC Buckingham's office up to the roof to power the cameras. All 8 cameras were positioned facing east over the Hudson River and surrounding highlands and horizon. The video cables were connected to a switcher with output to a monitor that sat on LTC Buckingham's desk at work.

For approximately 2 ½ weeks, the cameras provided images to the monitor on LTC Buckingham's desk so he could assess their performance in different weather environments. During that period, there were approximately 3 days of precipitation that allowed the team to discern camera performance in the rain.

7.2.4.2 Analysis of Data. The temperate climate test yielded two primary results. The first result centered around the effect of precipitation on optical quality of the cameras. The second regards a developing optical problem with several cameras, which began during the cold test, but was confirmed during the temperate test.

Precipitation – The only problem noted with precipitation was raindrops on the lenses of the cameras. Of the eight cameras used during the temperate test, only Cameras 3 and 7 listed below were immune from “water on the lens” problems. These two pinhole technology cameras experienced no negative optical characteristics due to precipitation primarily because they have no lens, and raindrops tend not to stick to the pinhole.

- Camera 3 – Micro Video MVC 3200 C Color Pinhole Camera
- Camera 7 – WATEC Board Camera

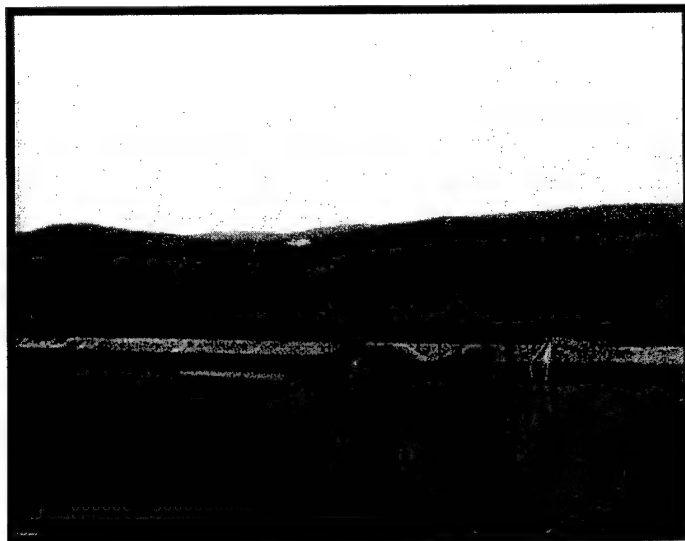


Figure 7.14 – Cadet Chris Green with Cameras positioned for Temperate Climate Test

Streaks – During the course of the cold weather test at CRTC, some of the cameras, which underwent the 30-day test at Bolio Lake, began to develop pink streaks in the field of view. These streaks were also noted when the cameras were tested during the hot weather. During the temperate test, it became clear that the streaks were building in intensity and clearly degrading the quality of the image. Figure 7.15 shows an image from one of the cameras displaying these streaks.



Figure 7.15 – Characteristic Pink Streaks in Image

Some degree of degradation from this characteristic was noted on the following cameras:

- Camera 4 - Color Bullet Long – (North American Video)
- Camera 5 - WATEC (LCL211)
- Camera 7 – WATEC Board Camera
- Camera 8 – Color Bullet Short (Marshall Electronics)

No specific cause for these streaks was determined, but all four of the cameras above experienced this idiosyncrasy to some extent. The primary concern with this optical problem is that the streaks actually appear to be an environmental phenomenon when they are actually an electronics issue. Thus they could be misinterpreted as vapor trails or clouds. This degradation of camera performance was taken into account when comparing the cameras for a final decision.

7.2.5 Shock Test. The DAMTA will descend and impact the ground at a rate of approximately 15 – 20 feet per second. The team felt it important to discern each camera's tolerance of shock to ensure it could withstand the DAMTA impact. Basic physics equations (Equation 1) shown below were used to determine the height from which the cameras should be dropped to create impact speeds of 15-20 fps.

$$\begin{aligned}
 d &= \frac{1}{2} at^2 \\
 V &= at \\
 d &= \frac{1}{2} a \left(\frac{v}{a} \right)^2 = \frac{1}{2} \frac{v^2}{a} = \frac{1}{2} \frac{v^2}{32.2}
 \end{aligned}
 \tag{1}$$

These equations were used to determine that dropping the cameras from 3.5 feet to the ground could simulate a 15 fps impact speed. Similarly dropping the cameras from a 6-foot elevation could simulate a 20 fps impact speed.

7.2.5.1 Conduct of Test. In order to simulate the impact of the DAMTA platform with the ground and the effect on the cameras, the research team conducted a simple drop test. All eight feasible cameras were attached to their respective tripods on the test stand. The two test stands were fastened together as shown in Figure 7.12 below so that all eight cameras could be dropped simultaneously.

The cameras were powered up and the camera images were displayed on a monitor in LTC Buckingham's office. The test stand was then dropped from different heights beginning at 1 foot and increasing by 1 foot each drop up to a 6-foot elevation above the ground. After each drop, the team noted any physical damage. In addition, the monitor was checked for any optical degradation or damage to the cameras. This was repeated at 1,2,3,4,5 and 6 feet. Figure 7.16 shows images from the test.

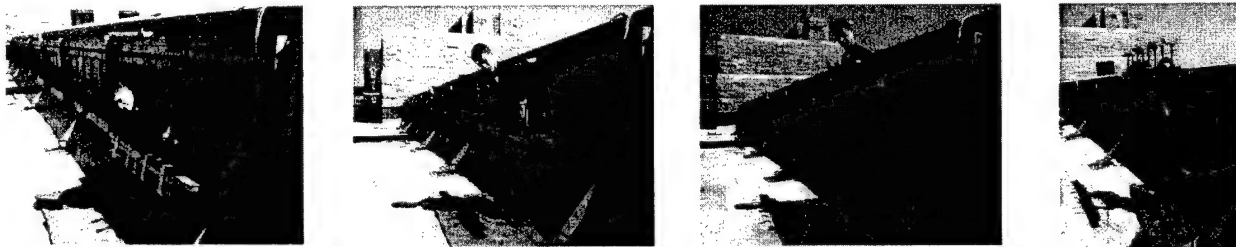


Figure 7.16 – Cameras being positioned for Shock Test at Various Heights

7.2.5.2 Results. Seven of the eight cameras performed flawlessly throughout the test and experienced no physical or optical damage after being dropped from heights simulating descent speeds up to 20 fps. One camera, the color bullet short camera made by Marshall, experienced a housing failure after the 5-foot level drop. The housing was repaired temporarily and the test was continued. During the 6-foot drop test, the camera housing failed again and the wiring for the electronics was damaged. This camera was deemed infeasible and dropped from further consideration as a result of the shock test.

7.3 Camera Selection. Subsequent to the cold weather test, hot weather test, temperate weather test and shock test, the team analyzed the data, which was gathered to begin the process of selecting the best off-the-shelf camera for the DAMTA application. The process consisted of a final feasibility screen, and Multi-Objective Decision Analysis (MODA).

7.3.1 Final Feasibility Screen. Table 7.2 provides a compilation of the final feasibility screen. Each of the cameras, which is marked with an "X" in column 4, was purchased and tested. Column 5 represents the results of the cold test in which three cameras (YC-100, High resolution black and white bullet and the Marshall Color Bullet) failed to pass the feasibility test. Column 6 indicates that none of the cameras were deemed infeasible due to the temperate test. Column 7 indicates that none of the cameras were deemed infeasible due to the hot/tropical test. Column 8 indicates that the Marshall color bullet failed the shock test. The last column in the table establishes that only 7 of the 24 cameras considered for this application were deemed feasible. These cameras are listed below:

- Camera 1 – Micro Video MVC 3000 H
- Camera 2 – Micro Video MV 2300
- Camera 3 – Micro Video MVC 3200 C Color Pinhole Camera
- Camera 4 - Color Bullet Long – (North American Video)
- Camera 5 - WATEC (LCL211)
- Camera 6 - WATEC (LCL217)
- Camera 7 – WATEC Board Camera

7.3.2 Multi-Objective Decision Analysis. The 7 feasible cameras were compared using MODA, which provides a method for comparing different alternatives quantitatively. Alternatives are compared using multiple criteria to help determine which best meets the needs of the decision-maker.

7.3.2.1 Raw Data Matrix. Table 7.4 is the raw data matrix that was developed for the comparison of feasible cameras to help determine the optimal camera for the DAMTA. The seven cameras are listed down the left side of the chart. The criteria listed across the top have been divided into two major categories: performance and physical characteristics. Performance is further subdivided into optical performance, field of view and lux rating. Optical performance is subdivided into cold test, temperate test and hot test. Similarly, the physical characteristics were subdivided into three major criteria: dimensions, weight and weatherability. Weights for each of the categories of criteria were developed based on the research teams understanding of the client's concerns. The raw data for each criterion has been entered in

the chart as a method of cataloging the quantities to be compared. Each of these categories of criteria are discussed below.

Performance – This category represents the ability of the camera to provide optical information for the user. It was weighted at 60% indicating that performance was somewhat more important than the camera's physical characteristics.

Optical Performance – This subcategory to performance indicates both the resolution and the clarity of the image. It was weighted at 75% indicating that optical performance is of primary importance compared to field of view and lux rating. Optical performance is measured in the three primary climatic conditions: cold, temperate and hot. Temperate was weighted the heaviest because most operations will be conducted in a temperate climate rather than one of cold or hot extremes. These three criteria are qualitative and had to be converted to a quantitative score.

Field of View – This subcategory to performance measures the width of the field of view of each camera in degrees. It was weighted 20% indicating it is about one-third as important as optical performance, but still four times as important as the lux rating. This criterion is quantitative.

Lux Rating – This subcategory to performance is a measure of the sensitivity to low light of each camera. One lux represents the light of one candle. It was weighted 5% representing the fact that our imagery enhancement with off-the-shelf cameras is primarily meant to be used in daylight. True night vision optics are anticipated to be too expensive for this application. This criterion is quantitative.

Physical Characteristics – This category represents the physical makeup of the cameras. This category was weighted at 40% indicating it is of lesser, but still substantive importance in the final decision as compared to Performance.

Dimensions – This subcategory of physical characteristics relates to the cameras' physical dimensions and shape and how well they will fit into the DAMTA platform as currently designed by ATI. It was weighted 40% indicating it is of equal importance to weight, and twice the importance of weatherability. This criterion is qualitative and must be converted to a quantitative score.

Weight – This subcategory of physical characteristics is simply a measure of the physical weight of one camera. It is also weighted at 40%. This criterion is quantitative.

Weatherability – This subcategory of physical characteristics represents how well the cameras are packaged to withstand the physical elements and specifically, precipitation. It was weighted 20% indicating that it is half as important as the dimensions and the weight. This is primarily because it must only weather the elements for 30 days before it is abandoned. This criterion is qualitative and had to be converted to a quantitative score.

Table 7.4 – Raw Data Matrix

Camera Type	Performance 60%					Physical Characteristics 40%		
	Optical Performance 75%			Field of View 20%	Lux Rating 5%	Dimensions 40%	Weight 40%	Weatherability 20%
	Cold Test 30%	Temperate Test 40%	Hot Test 30%					
Color Bullet CCD	Excellent below -30	Trouble with Precipitation	Excellent Above 80	70°	0.05	Circular, 80mm deep	125	Waterproof, seal around lens
WATEC LCL 211	Frost on Lens, Loss of Clarity	Trouble with Rain, Water in Lens	Purple Streaks in Image Above 80	100°	2.0	Big, bulky, 80mm deep	200	Need to seal lens and adjustments
WATEC LCL 217	Frost on Lens, Loss of Clarity	Precipitation Trouble, Water in Lens	Excellent Above 80	100°	1.0	Big, bulky, 80mm deep	200	Need to seal lens and adjustments
WATEC Board	Excellent, Slight Frost	Trouble with Precipitation	Excellent Above 80	70°	0.1	1/3" square, board camera	40	No waterproofing
Micro Video MVC3000H	Excellent below -30	Trouble with Precipitation	Excellent Above 80	70°	0.5	Circular, 1" diameter, 2.5" long	150	Waterproof, seal around lens
Micro Video MV 2300	Excellent below -30	Trouble with Precipitation	Excellent Above 80	70°	0.5	Circular, 7/8" diameter, 2.75" long	115	Waterproof, seal around lens
Micro Video MVC 3200C Pinhole	Excellent below -30, No Frost	Perfect Performance	Excellent Above 80	60°	0.5	32mm square, 10mm deep	25	Waterproof, seal pinhole

7.3.2.2 Scoring. Having established the raw data matrix, each of the entries were converted to a quantitative score so that the final weighted scores of each camera could be computed and compared. Utility curves were developed for the quantitative measure. These curves convert the raw quantity into a score between 1 and 10 based on the research teams' understanding of the decision-makers preferences. Tables were developed for the qualitative measures to convert each of these raw measures into a score between 1 and 10. Tables 7.5 and 7.6 show the scoring tables for the 5 qualitative criteria.

Table 7.5 – Scoring Tables: Cold Test, Temperate Test, Hot Test

Optical Performance		
Cold Test	Temperate Test	Hot Test
10 Withstood temperatures below -30°F with no image degradation and no frost on the lens	10 Withstood a range of temperature from 20°F-70°F with no image degradation and no decrease in picture quality during precipitation	10 Withstood temperatures above 80°F with no image degradation or condensation on the lens
8 Withstood temperatures below -30°F with slight image degradation and slight frost on the lens	8 Withstood a range of temperature from 20°F-70°F with slight image degradation and a slight decrease in picture quality during precipitation	8 Withstood temperatures above 80°F with slight image degradation and condensation on the lens
6 Withstood temperatures below -30°F with noticeable image degradation and noticeable frost on the lens	6 Withstood a range of temperature from 20°F-70°F with a noticeable image degradation and a noticeable decrease in picture quality with precipitation	6 Withstood temperatures above 80°F with noticeable image degradation and condensation on the lens
4 Withstood temperatures below -30°F with serious image degradation and frost covering half the lens	4 Withstood a range of temperature from 20°F-70°F with serious image degradation and large decrease in picture quality with precipitation	4 Withstood temperatures above 80°F with serious image degradation and condensation on the lens
2 Failed to withstand temperatures below -30°F and had serious image degradation and frost covering the lens	2 Failed to withstand range of temperature from 20°F-70°F with no image degradation and no decrease in picture quality with precipitation	2 Failed to withstand temperatures above 80°F and had serious image degradation and condensation on the lens

Table 7.6 – Scoring Charts: Dimensions and Weatherability

Dimensions		Weatherability	
10	The dimensions of the camera are such that the height and radius of the mounting bracket are at an absolute minimum and the camera can easily be mounted inside the circular bracket.	10	Factory packaging provides a waterproof seal and the internal circuits are unaffected when left exposed to the elements for extended periods of time.
8	The dimensions of the camera are such that the height and radius of the mounting bracket are nearly minimized and the camera can be mounted inside the circular bracket.	8	Factory packaging is mostly waterproof and requires little additional resources to make it fully waterproof and safe from precipitation
6	The dimensions of the camera dictate the radius of the mounting bracket are the size of the DAMTA can and the camera can easily be mounted inside the circular bracket.	6	The camera has some waterproofing which keeps the circuits somewhat from being damaged and requires additional waterproofing before long exposure.
4	The dimensions of the camera dictate the radius of the mounting bracket are the size of the DAMTA can and the camera is difficult to mount inside the bracket.	4	The camera has little waterproofing which keeps the circuits from being damaged by precipitation. It requires additional material to make it fully waterproof
2	The dimensions of the camera require a high mounting bracket with a radius bigger than the 69.85 mm of the DAMTA can and it is difficult to mount the camera inside the bracket.	2	The camera is not waterproof upon purchase and internal circuits are extremely susceptible to damage from precipitation.

Entries in the raw data matrix were compared with these tables to ascertain the appropriate quantitative value to place in the final MODA matrix. These tables were designed to represent the teams' understanding of the importance to the decision-maker of each measure.

Figure 7.17 shows the 3 utility curves used for the 3 quantitative measures: Field of View, Lux Rating and Weight. Each of these curves is described below:

Field of View (Figure 7.17a) – This chart relates the horizontal field of view in degrees with a score of 1 to 10. In general, the greater the field of view, the greater the score. A field of view for one camera of 120 degrees represents complete coverage of the horizon with 3 cameras. Three cameras was chosen as the default number for the DAMTA for several reasons. First, it provides some redundancy in the case of a single camera failure. Second, most of the cameras tested had a field of view between 60 and 100 degrees, thus three cameras provides a total field of view for the DAMTA between 180 to 300 degrees which represents somewhere between 50% and 83% of the total horizon. This coverage was determined to be sufficient to gather a fairly accurate representation of the weather in the four cardinal directions. Third, any number of cameras greater than three begins to increase the cost beyond \$750 which appears to be an appropriate limit for the cameras in an imagery enhanced DAMTA. Referring again to the curve in Figure 7.17, we see that the highest score is given to a camera with a 120-degree field of view, which represents complete coverage with three cameras. Below 60 degrees of coverage, the utility drops quickly because we have visual coverage of less than half the horizon with three cameras.

Lux Rating (Figure 7.17b)– This exponentially decreasing curve represents the fact that the utility of the cameras in low light drops quickly as lux ratings increase from .05 to 5.0. One lux represents the

light of one candle essentially. Although the imagery enhanced DAMTA is intended primarily to provide weather intelligence during daylight hours, a low lux rating assists in gathering information at dawn and dusk, thus extending the useful time cameras on the DAMTA can be employed each day. Lux ratings of 1.0 and lower provided quickly increasing utility for the DAMTA application.

Weight (Figure 7.17c) – This reverse s-curve represents the fact that total camera weights of .55 pounds or more located at the 6 to 7 foot mark on the DAMTA platform would begin to significantly impact stability of the platform on the ground. Thus, individual camera weights of less than 85 grams (0.18 lbs) were ideal. Weights great than 85 grams demonstrated quickly deteriorating utility to the designer.

The raw scores for each of these criteria for each camera were converted into values of 1 to 10 and entered into the MODA matrix as shown in Figure 7.17

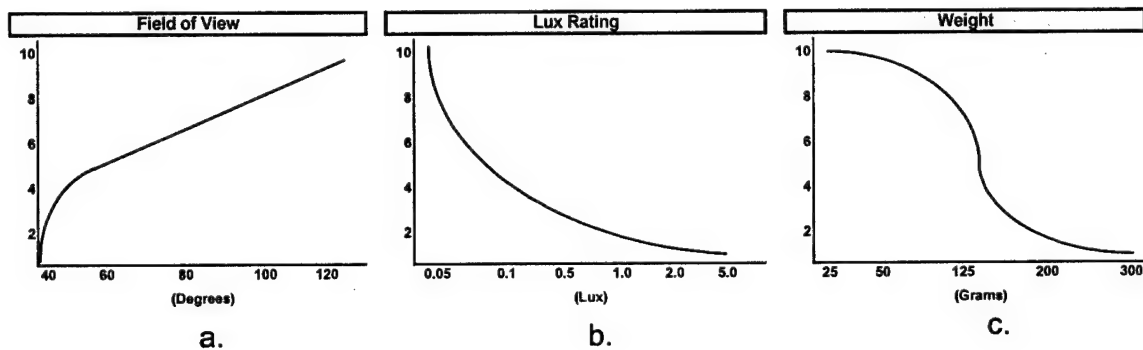


Figure 7.17 – Utility Curves: Field of View, Lux Rating, and Weight

7.3.2.3 MODA Matrix. This matrix shown in Figure 7.18 documents the final scores for each camera for each of the criteria indicated above. The seven feasible cameras are listed down the left side. The major categories and their subcategories are listed across the top with their respective weights. The total score in the far right column represents the weighted sum of the individual scores taking into account the criteria weights. The Micro Video 3200 C Pinhole had the highest score.

Camera Type	Performance 60%					Physical Characteristics 40%			Numerical Evaluation Score	Cost
	Optical Performance 75%			Field of View 20%	Lux Rating 5%	Dimensions 40%	Weight 40%	Weatherability 20%		
	Cold Test 30%	Temperate Test 40%	Hot Test 30%							
Color Bullet CCD	8	6	8	6	10	4	9	8	6.98	\$120.00
WATEC LCL 211	4	4	4	8	2	2	2	6	3.94	\$450.00
WATEC LCL 217	4	4	8	8	4	2	2	6	4.54	\$450.00
WATEC Board	8	6	8	5	1	8	10	2	6.91	\$300.00
Micro Video MVC3000H	8	6	8	5	3	6	6	8	6.49	\$249.00
Micro Video MV/2300	8	6	8	5	3	4	6	8	6.17	\$249.00
Micro Video MVC 3200C Pinhole	8	10	8	5	3	10	10	8	8.49	\$239.00

Figure 7.18 – Multi-Objective Decision Analysis Matrix

This total score represents all of the pertinent decision factors except cost. Cost was not integrated directly into the MODA matrix. Instead, a final chart comparing MODA scores with cost was produced. This chart is shown in Figure 7.19.

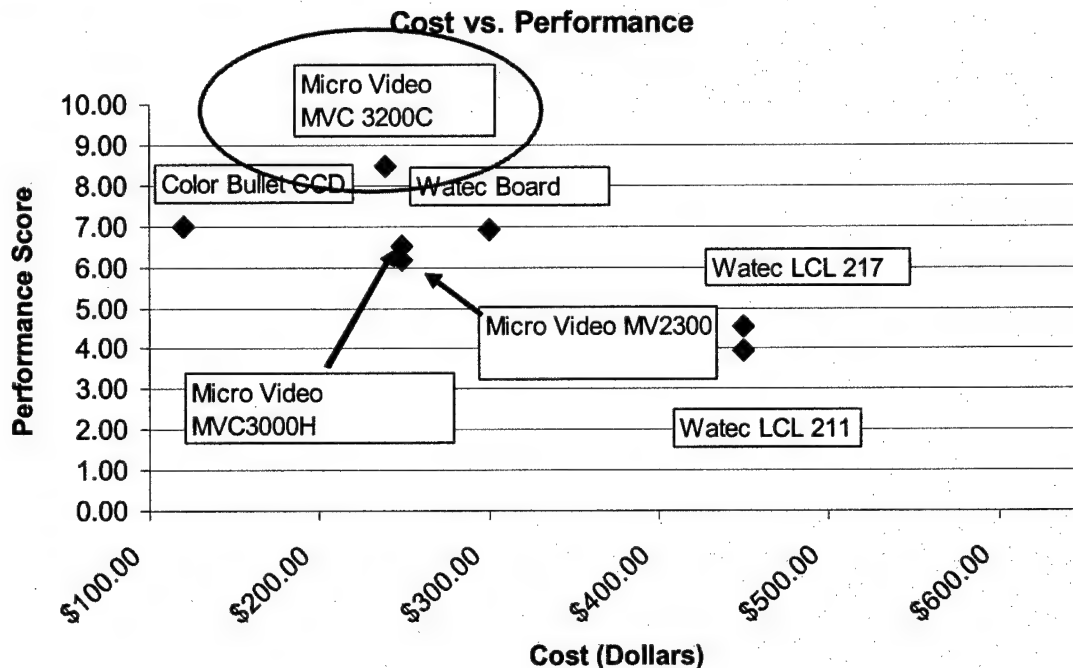


Figure 7.19 – MODA Scores versus the Cost of Each Individual Camera

The MVC 3200 C Pinhole camera clearly has the highest performance score (8.49). Since all the cameras to the right of it on the chart have lesser scores and higher costs, the MVC 3200 C clearly dominates those five cameras. The color bullet camera from North American Video has a lesser score, but also costs approximately half as much (\$120 versus \$240). Communication with the dealer of the MVC 3200 C indicates that if purchased in bulk, we could buy each of these at a cost less than \$200. Thus, a three-camera package would cost under \$600 and be within our anticipated cost constraint. Since both cameras fall under our constraint, our initial determination was that the MVC 3200 C was preferred. Prior to making a final determination, the team conducted a sensitivity analysis.

7.3.2.4 Sensitivity Analysis. Sensitivity analysis assists the decision-maker by determining how sensitive the final score is to changes in either weights or scores used in the matrix. If, in the process of determining weights and crafting utility curves and scoring tables, our technical work did not accurately represent the decision-makers interests, sensitivity analysis will help us determine how much leeway we have in varying these values before it changes the decision.

Only the weights in the MODA matrix were varied for this analysis. The weight on each individual criterion was varied by +/- 10%. Weights of other criterion on the same level were varied to ensure they summed to 100% and the resulting affect on the score was observed. These results are shown in Table 7.7. Column 1 indicates which criterion weight was varied. Column 2 specifies which camera had the highest score when the criterion weight was varied. Column 3 indicates the score for the winning camera when the weight was varied +10%. Column 4 indicates the score for the winning camera when the weight was varied -10%. Column 6 indicates the difference between the scores of the 1st and 2nd place cameras when the weights were varied.

The clear conclusion of the sensitivity analysis is that the MVC 3200 C Pinhole camera scores highest even if the individual criterion weights are varied by +/- 10%. The decision is most sensitive to lux rating. When this criterion is varied, the Color Bullet camera comes within 0.6 points of the MVC 3200 C Pinhole.

Table 7.7 – Tabulated Values from Sensitivity Analysis

Criterion Weight Varied	Camera with Highest Score	Score with Criteria Wt Varied by +10 %	Score with Criteria Wt Varied by -10 %	Minimum Difference in Scores between MVC 3200 C and Color Bullet
Performance	MVC 3200 C Pinhole	8.49	8.68	1.30
Optical Performance	MVC 3200 C Pinhole	8.74	8.24	1.28
Field of View	MVC 3200 C Pinhole	8.27	8.94	1.28
Lux Rating	MVC 3200 C Pinhole	7.57	8.89	0.6
Dimensions	MVC 3200 C Pinhole	8.65	8.33	1.23
Weight	MVC 3200 C Pinhole	8.65	8.33	1.23
Weatherability	MVC 3200 C Pinhole	8.41	8.57	1.37
Cold Test	MVC 3200 C Pinhole	8.31	8.67	1.15
Temperate Test	MVC 3200 C Pinhole	8.58	8.40	1.33
Hot Test	MVC 3200 C Pinhole	8.31	8.67	1.15

7.3.2.5 – Decision. Having completed the MODA Matrix and the sensitivity analysis, the team decided that the MVC 3200 C Pinhole Camera should be recommended as the best camera overall for the DAMTA application. This camera is available through Micro Video of Canada at www.microvideo.ca. It is pictured in Figure 7.20. This camera measures approximately 1.25 x 1.25 x .375 inches.

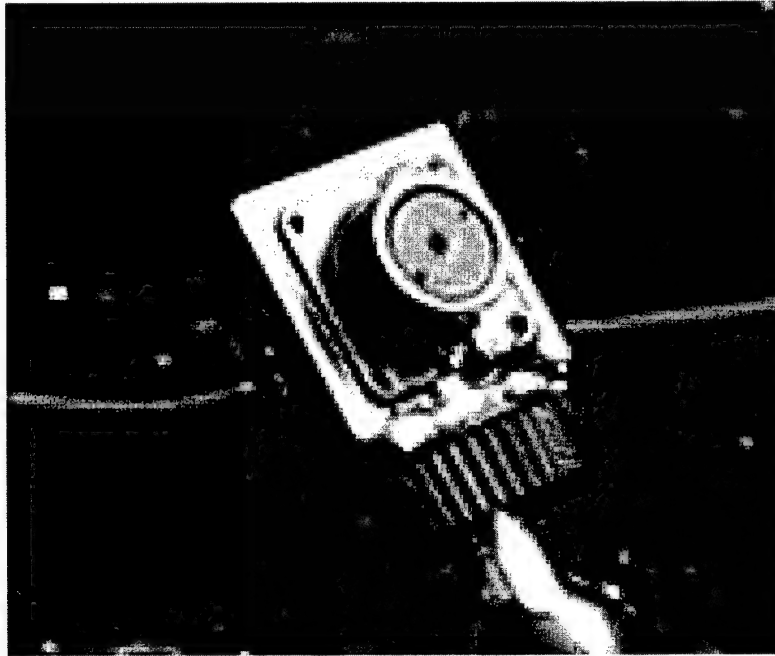


Figure 7.20 – MVC 3200 C Pinhole Camera

Having completed the process of camera selection, Section 8 outlines the methodology used in integrating the camera with the DAMTA platform.

Section 8 – Hardware Integration with DAMTA Platform

ATI produced its first DAMTA prototype in November 2002. This research group has been working since August 2002 to determine the right off-the-shelf camera to use on the DAMTA. This section documents the process used to integrate the two. That is, given the MVC 3200 C Pinhole camera, and a fairly mature DAMTA prototype, the team worked to design an appropriate way to mount the cameras on the prototype.

8.1 Design Overview. The design process used for this phase of the project was somewhat informal. This section provides an understanding of how the design was produced but does not seek to formalize the process. True creative design cannot always be reduced to a sequential process. This was the case with the integration of the selected camera and the DAMTA platform.

8.2 Concurrent Engineering. The physical design for the DAMTA prototype was initiated in the spring of 2002 when a research team from USMA conducted a four-month study under the auspices of the Army Research Labs to bound the problem of designing the mechanical portion of the DAMTA platform. A rough prototype was constructed based off of that study and is shown in Figure 8.1. The conclusions of that study were both briefed and provided in written media to ARL. ARL passed the report to ATI, who was awarded the contract to research and build the DAMTA in the summer of 2002. The study conducted by Cadet Green at ARL in June 2002 represented the initial research into augmenting the DAMTA platform with imagery sensors.



Figure 8.1 – Original DAMTA Model Produced at USMA – Spring 2002

From July 2002 through April 2003 both ATI and the research group at USMA worked concurrently designing the DAMTA platform and the imagery enhancement to that platform respectively. In November 2002, ATI produced its first prototype platform as shown in Figure 8.2

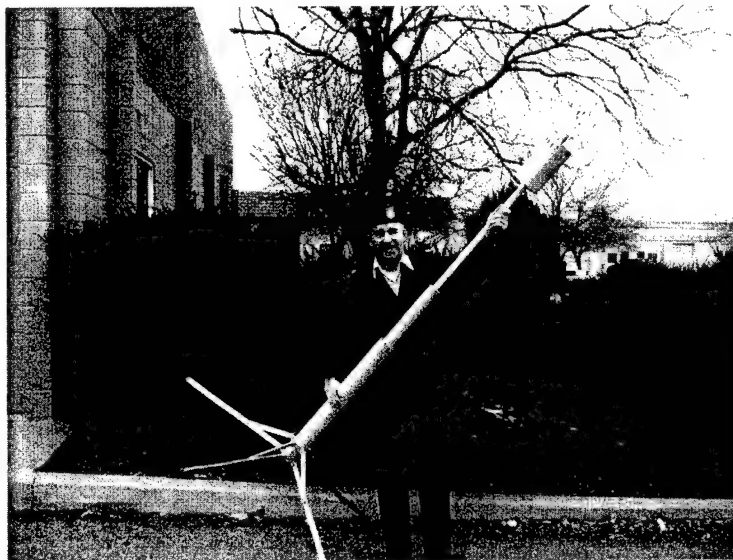


Figure 8.2 – DAMTA Prototype Produced by ATI – Fall 2002

The USMA team was just in the process of beginning the climatic testing phases, which continued through mid-April 2003. In February 2003, the USMA team began to get some idea of the cameras that would likely be finalists in the competition to determine which would be recommended for the DAMTA.

Two types of cameras emerged as the most competitive, they were the board cameras and the bullet cameras. The team then began in earnest considering methods of mounting the cameras on the ATI prototype.

8.3 Design Considerations. There were several primary considerations imposed on the design:

Location – It was clear that the cameras must be positioned near the top of the DAMTA platform in order for them to see the horizon.

Modularity – Since the basic DAMTA was not required to provide imagery, the team determined that a modular addition to the standard DAMTA prototype would be the most flexible way to augment it with imagery. The intent was to replicate a piece of the “can” at the top of the platform and mount the cameras in it. If a specific mission called for an imagery enhanced DAMTA, then the modular camera section could simply be added to the existing “can.” This modularity concept seemed to support the view that the module should be geometrically similar to the “can” at the top of the DAMTA.

Quantity of Cameras – Given that we had previously determined that a 3-camera group was both economically and technically best, we decided to space these still video cameras at 120 degrees around the “can” to provide a near-full panoramic view of the surroundings. The total coverage in degrees would be dependent upon the selected camera’s field of view.

8.4 – Prototype Design and Construction. With these design considerations in mind, initial sketches were drawn to capture these aspects of location, modularity and quantity. The sketches were converted to 3D digital drawings as shown in Figure 8.3.

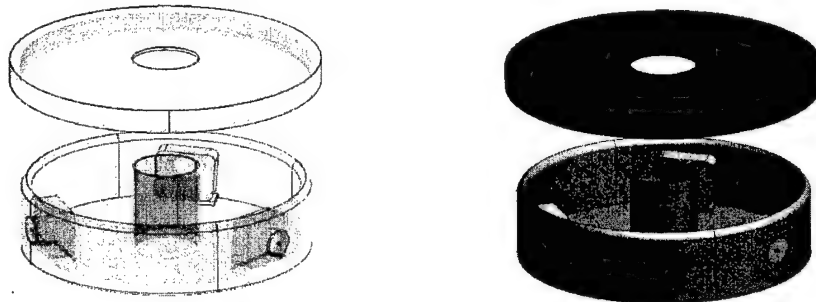


Figure 8.3 – Initial 3D Drawings of Imagery Module

These drawings were then sent to a 3D printer to produce an initial prototype in plastic. This prototype with the Micro Video MVC 3200 C Pinhole cameras mounted in it are shown in Figure 8.4. Similar drawings and a prototype were constructed for another modular option using a bullet type camera.

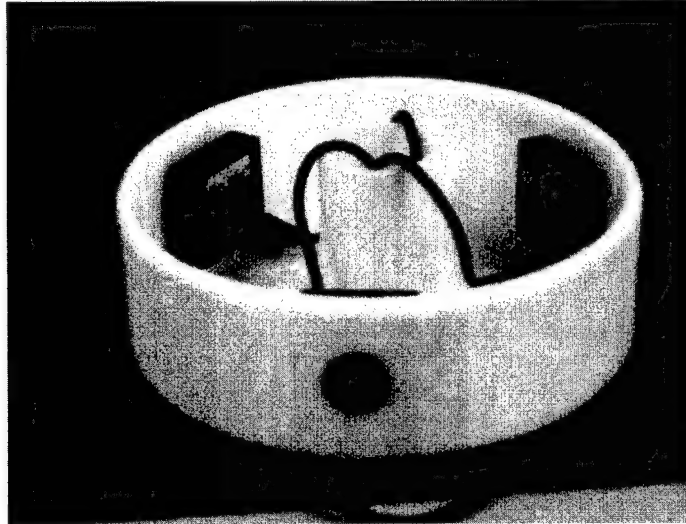


Figure 8.4 – Plastic Prototype of Modular Imagery Enhancement to DAMTA

8.5 Client Feedback. At this point in the design process, the USMA team briefed ARL at White Sands Missile Range to get their input on the prototype. Dr. Doug Brown, chief of the Battlefield Environment Division of ARL in Adelphi, MD sat in on the briefing through VTC. He was very pleased with our efforts and surprised that we had actually produced a prototype at this point.

Based on feedback from ARL, the team sought to construct a model of the DAMTA platform upon which we could mount the cameras. ATI also provided excellent feedback at this point indicating that the modular addition was not required and that we could produce three “ports” for the cameras directly at the top of the “can”. The team had avoided this temptation out of concern that the cameras would displace room required for ATIs electronics. This simplified the design and allowed the team to go forward with the model.

8.6 Model Construction. Drawings and photographs were provided to the Fabrications Section of the Directorate of Information Management at USMA. In two weeks they produced a model of the DAMTA, which could be outfitted with the MVC 3200 C pinhole cameras. Photographs of this model are shown in Figures 8.5, 8.6 and 8.7.



Figure 8.5 – DAMTA Model with Imagery Enhancement – Full View

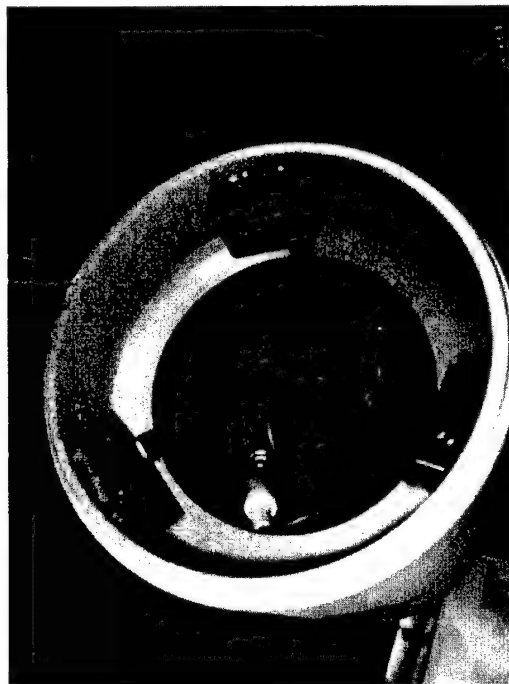


Figure 8.6 – Top of DAMTA ‘Can’ Showing Camera Placement

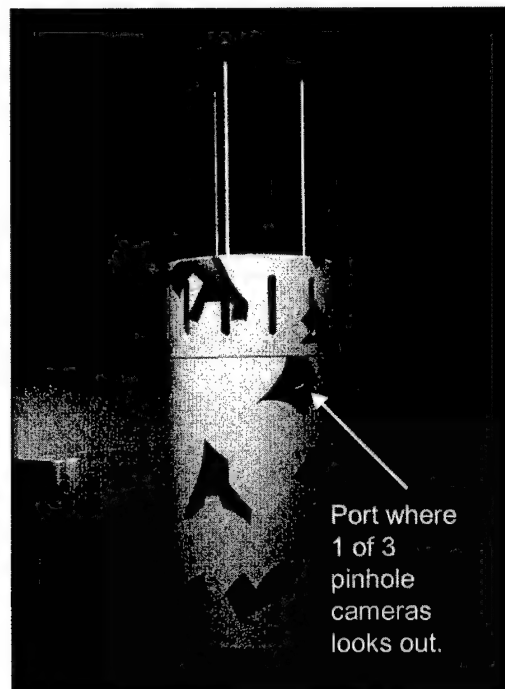


Figure 8.7 – DAMTA “Can” with MVC 3200 C Pinhole Camera Port

This modified design process produced a simple, efficient, and sleek solution to integrating the selected camera with the latest version of the ATI prototype.

8.7 Benefits to Final Design.

This design provides several benefits:

- It flush mounts the cameras with the outside of the DAMTA “can” minimizing damage to the cameras.
- It allows sufficient room in the top of the DAMTA “can” for other standard sensor electronics.
- It puts the cameras within four inches of the top of the DAMTA, and thus over 6 feet off the ground, for excellent visibility.
- It provides a total panorama of approximately 180 degrees, which is half of the horizon.
- It minimizes the effects of precipitation on the camera optics as the pinhole cameras have no lens.
- It relieves the requirements for a separate modular “imagery sensor” piece and instead incorporates the cameras into the existing “can”.

Section 9 – Conclusions and Recommendations

This study has been rewarding and revealing. The results are being provided to ARL, to UPOS and to ATI. While ATI is not yet fully engaged in addressing the imagery enhancement to the DAMTA, we anticipate that this work will be beneficial in helping them address this issue in the coming months. Based on meetings in December 2002, ATI anticipates that a completely custom solution to imagery enhancement may be warranted in the future. This may involve a unique camera design, which is not commercially available off-the-shelf. It may also involve a package with integrated electronics to conduct the frame grabbing and compression of images. However, the study contained herein provides good background information, which may be readily dovetailed with any fresh design ideas in the coming months.

This section is divided into three parts consistent with the three primary goals of the project: 1) To determine the benefits that will accrue to the army through the use of an imagery enhanced DAMTA; 2) to determine a specific off-the-shelf camera most suited to integration with the DAMTA; 3) to construct a prototype demonstrating the best method of integrating cameras with the DAMTA platform.

9.1 Benefits of an Imagery Enhanced DAMTA. It is difficult to accurately measure the value added by placing imagery on the DAMTA platform. We do know that based on our survey and development of the prototype that imagery can have a profound affect on accurately forecasting weather by visualizing and verifying raw weather data and enhancing the commander's knowledge about the tactical situation. The benefits of imagery provide increased situational awareness for commanders and staffs within specific environments. The ability to see the impacts of weather, terrain and the environment is critical for leaders at all levels. Imagery will reduce loss of life during tactical operations by minimizing mission failures (*mission failure avoidance*), and providing the opportunity to plan and execute missions better than with only raw weather data.

Imagery will assist in properly deploying assets on the battlefield by allowing other tactical resources to do other mission essential tasks, and it is possible to reuse the DAMTA platform if the tactical operations allows. Imagery as a capability increases the *trust* in the weather collection and forecast system used by operation centers. *Information Assurance* (IA) is a key component in situational awareness and moving information around the battlefield. IA is the *trust* that information presented by the system is accurate and is properly represented; its measure of the level of acceptable risk depends on the critical nature of the system's mission [Longstaff and Haimes, 2000].

The DAMTA platform with integrated imagery will reduce costs for: 1) equipment in terms of dollars and wear and tear consequently decreasing the mean time to failure of components; 2) personnel in terms of lives, dollars, and time consequently increase efficiency, forecasting and battlefield superiority

and 3) mission failures in terms of operational momentum and time to complete objectives. Predicting weather and tactical changes may lead to canceling operations when the risk exceeds a commander's threshold or continuing with operations when weather and tactical advantages (momentum) can be taken. DAMTA may also recoup design and implementation costs by allowing other communities and disciplines (like those discussed in Section 5) to use its technology and functionality.

9.2 Recommendation of a Specific Camera. The research team recommends the use of the Micro Video MVC 3200 C Pinhole camera for this application. The justification for this recommendation is provided in Section 7. This camera is available through Micro Video at www.microvideo.ca. Their mailing address is: Bobcaygeon, Ontario, CANADA - K0M 1A0. Their e-mail contact is info@microvideo.ca. Their phone contact numbers are: phone: 1 (705) 738-1755 or Toll Free: 1 (800) 213-8111. FAX: (705) 738-5484. These cameras cost approximately \$239.00. Bulk costs will be less than \$200 each.

9.3 Recommendation of Method to Integrate Cameras with DAMTA Platform. Section 8 establishes that three small cameras spaced 120 degrees apart near the top of the DAMTA "can" and integrated with that "can" are idea. This configuration provides the best possible view, provides adequate coverage of the horizon, and optimizes the placement of sensors and electronics at the top of the platform.

The model produced at USMA is shown in Figures 8.5, 8.6 and 8.7. It is a sleek, efficient and inexpensive design. It was displayed and demonstrated on 8 May 2003 to Mr. Ed Creegan from ARL-WSMR. It was also used in a briefing presented to Mr. Walt Hollis, Deputy Undersecretary of the Army for Operations Research on 9 May 2003 at USMA.

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Appendix A: Project Schedules

The following *four* pages outline the project tasks for both the Hardware group (first three pages; project labeled “Imagery Enhancement (bottom left)”) and the Systems Integration Group (fourth page; project labeled DAMTA Benefits (bottom left)”). Microsoft Project was used to track task duration, start and finish dates, resources and predecessors for all related project tasks.

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names	21	24	27	30	2	5	8	11	14	17
1	Purchase Hardware - Phase 1	26 days	Wed 8/28/02	Thu 10/3/02			8/28									
2	Order Digital Camera	0 days	Wed 8/28/02	Wed 8/28/02			8/28									
3	Order Hardware (Phase I)	0 days	Wed 8/28/02	Wed 8/28/02			8/28									
4	Receive Digital Camera	1 day	Mon 9/9/02	Mon 9/9/02	2FS+7 days											
5	Phase 1 Order Received	0 days	Thu 9/26/02	Thu 9/26/02	3FS+21 days	Green[126%]										
6	Phase 1 Hardware Organized	5 days	Fri 9/27/02	Thu 10/3/02	5											
7	Create schedule for year	15 days	Tue 9/3/02	Mon 9/23/02		Buckingham	9/3									
8	Create task list for Hardware	10 days	Tue 9/3/02	Mon 9/16/02			9/3									
9	Create task list for System Integration	10 days	Tue 9/3/02	Mon 9/16/02			9/3									
10	Put tasks into MS Project	5 days	Tue 9/17/02	Mon 9/23/02	8,9,16											
11	Schedule Tests	10 days	Tue 9/3/02	Mon 9/16/02			9/3									
12	Initial coordination for Cold Test	1 day	Tue 9/3/02	Tue 9/3/02		Buckingham	9/3									
13	Initial coordination for Hot Test	1 day	Mon 9/16/02	Mon 9/16/02	16	Buckingham										
14	Initial coordination for Tropical Test	1 day	Mon 9/16/02	Mon 9/16/02	16	Buckingham										
15	Contact CECOM Night Vision Labs reference can	1 day	Tue 9/3/02	Tue 9/3/02		Buckingham	9/3									
16	MS Project 2000 Conference	4 days	Tue 9/10/02	Fri 9/13/02		Buckingham										
17	Purchase Hardware - Phase 2	50 days	Mon 9/16/02	Tue 11/26/02	16											
18	Review Cadet Green's Work	4 days	Tue 9/24/02	Fri 9/27/02	7	Buckingham										
19	Determine selection criteria for testing came	2 days	Mon 9/30/02	Tue 10/1/02	18	Green,Buckingham										
20	Select cameras to test	30 days	Wed 10/2/02	Thu 11/14/02	19	Green,Buckingham										
21	Order Cameras, tools and monitor for testing	1 day	Fri 11/15/02	Fri 11/15/02	20,6	Green,Buckingham										
22	Phase II Order Organized	2 days	Mon 9/16/02	Tue 9/17/02												
23	Phase II Order Received	0 days	Tue 11/26/02	Tue 11/26/02	21FS+7 days,22											
24	Submit September Monthly Report	0 days	Mon 9/30/02	Mon 9/30/02		Bailey										
25	ASEM Conference Presentation	3 days	Wed 10/2/02	Fri 10/4/02		Green,Buckingham										
26	Submit October monthly report	0 days	Thu 10/31/02	Thu 10/31/02		Bailey										
36	Conduct intermediate briefing with WSMR in the f	2 days	Wed 11/20/02	Thu 11/21/02		Buckingham										
37	Visit ATI in Colorado Springs	2 days	Wed 11/20/02	Thu 11/21/02		Buckingham										
38	Submit November monthly report	0 days	Fri 11/29/02	Fri 11/29/02		Bailey										

Task

Critical Task

Progress

Milestone

Summary

Rolled Up Task

Rolled Up Critical Task

Rolled Up Milestone

Rolled Up Progress

Split

External Tasks

Project Summary

Group By Summary

Project: Imagery Enhancement to DAI
Date: Thu 5/15/03

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names	21	24	27	30	5	8	11	14	17
							September 2002								
27	Conduct Preliminary Test of Cameras	52 days	Wed 9/18/02	Wed 12/4/02		Buckingham, Green								9/18	
28	Determine how to test optical clarity	2 days	Wed 11/27/02	Mon 12/2/02	23	Buckingham, Green									
29	Determine additional hardware required to test	2 days	Wed 9/18/02	Thu 9/19/02	22	Buckingham, Green								9/18	
30	Determine how to test low light capability	2 days	Tue 12/3/02	Wed 12/4/02	28	Buckingham, Green									
31	Order additional hardware for test	1 day	Fri 9/20/02	Fri 9/20/02	29									9/20	
32	Receive additional hardware for test	0 days	Fri 10/4/02	Fri 10/4/02	31FS+10 days										
33	Establish cold weather test procedures	3 days	Mon 10/7/02	Wed 10/9/02	32	Buckingham, Green									
34	Set up preliminary test apparatus	3 days	Thu 10/10/02	Tue 10/15/02	33	Buckingham, Green									
35	Conduct home station test of cameras	5 days	Wed 10/16/02	Tue 10/22/02	33,34	Buckingham, Green									
40	Submit December monthly report	0 days	Tue 12/31/02	Tue 12/31/02		Bailey									
41	Contact CME reference having a cadet assist with	9 days	Mon 1/13/03	Fri 1/24/03		Buckingham									
42	Cold Weather Test	5 days	Mon 1/13/03	Fri 1/17/03		Buckingham, Green									
43	Analyze Cold Test Data	10 days	Mon 1/20/03	Mon 2/3/03	42	Buckingham, Green									
44	Consider Methods for Orienting Cams (Planning, etc)	10 days	Mon 1/20/03	Mon 2/3/03		Buckingham, Green									
39	End of Term Briefing/Interim Report	0 days	Tue 10/22/02	Tue 10/22/02	35	Bailey, Bunt, Green									
45	Submit January monthly report	0 days	Fri 1/31/03	Fri 1/31/03		Bailey									
46	Investigate placement of camera on DAMTA	1 day	Tue 2/4/03	Tue 2/4/03	44	Buckingham, Green									
47	Conduct Hot Weather Test	4 days	Tue 2/4/03	Fri 2/7/03	43	Buckingham									
48	Analyze Hot Test Data	1 day	Mon 2/10/03	Mon 2/10/03	47										
49	Conduct Tropical Test	4 days	Tue 2/11/03	Fri 2/14/03	48	Buckingham									
50	Conduct feasibility screening of cameras	5 days	Mon 2/17/03	Mon 2/24/03	49	Buckingham, Green									
51	Analyze Tropical Test Data	1 day	Tue 2/18/03	Tue 2/18/03	49										
52	Create Multi-Objective decision matrix for camera	5 days	Tue 2/25/03	Mon 3/3/03	50	Buckingham, Green									
53	Submit February monthly report	0 days	Fri 2/28/03	Fri 2/28/03		Bailey									
54	Do utility versus cost plot for selection of camera	5 days	Tue 3/4/03	Mon 3/10/03	52	Buckingham, Green									
55	Integrate hardware piece with application piece	5 days	Tue 3/11/03	Mon 3/17/03	54	Bunt, Green, Buckingham									
56	Outbrief ATI	3 days	Tue 3/11/03	Thu 3/13/03	54	Buckingham, Lamm									
57	Conduct intermediate briefing with WSMR in the field	3 days	Mon 3/17/03	Wed 3/19/03	54	Bunt, Green, Buckingham									
58	Final Report - 1st Half	15 days	Tue 3/18/03	Mon 4/7/03	55										

Project: Imagery Enhancement to DAI
Date: Thu 5/15/03

Task

Critical Task

Progress

Milestone

Summary

External Tasks

Project Summary

Group By Summary

Rolled Up Task

Rolled Up Critical Task

Rolled Up Milestone

Rolled Up Progress

Split

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names	21	24	27	30	2	5	8	11	14	17
59	Submit March monthly report	0 days	Mon 3/31/03	Mon 3/31/03		Bailey										
60	Final Report - Last Half	5 days	Tue 4/8/03	Mon 4/14/03	58	Bunt, Green, Bailey										
61	Submit April monthly report	0 days	Wed 4/30/03	Wed 4/30/03		Bailey										
62	Outbrief ARL-WSMR on project day	1 day	Thu 5/8/03	Thu 5/8/03		Bailey, Bunt, Green										
63	Submit May monthly report	0 days	Fri 5/30/03	Fri 5/30/03		Bailey										

Project: Imagery Enhancement to DAM Date: Thu 5/15/03	Task	Rolled Up Task	External Tasks
Critical Task		Rolled Up Critical Task	Project Summary
Progress		Rolled Up Milestone	Group By Summary
Milestone		Rolled Up Progress	
Summary		Split	

ID	% Complete	Task Name	Duration	Start	Finish	Predecessors	25, '02	Sep 1, '02	Sep 8, '02
17	100%	Set Project Deadlines and key dates	1 day	Fri 8/30/02	Fri 8/30/02		M	S	S
18	100%	Willis/Davis Tech. Report	1 day	Tue 8/27/02	Tue 8/27/02		T	S	S
20	100%	LTC Buckingham's Final Report (receive)	2 days	Tue 9/3/02	Wed 9/4/02		W	T	S
1	100%	Build Database	8 days	Wed 8/28/02	Fri 9/6/02		T	T	S
8	100%	Get Fort Knox Sensor Data	2 days	Mon 9/16/02	Tue 9/17/02		W	T	S
5	100%	Research Past Work	5 days	Mon 9/16/02	Fri 9/20/02		T	T	S
6	100%	Research Current Work	5 days	Mon 9/16/02	Fri 9/20/02		T	T	S
2	60%	Stakeholder Analysis	17 days	Mon 9/23/02	Tue 10/15/02		T	T	S
3	15%	Build DAMTA Benefits Survey (Web Based Survey)	8 days	Mon 9/23/02	Wed 10/2/02		T	T	S
4	100%	Affinity Diagram	9 days	Thu 10/3/02	Tue 10/15/02	3	T	T	S
21	100%	CPT Lamm's Sensor Report (receive)	7 days	Fri 10/11/02	Sun 10/20/02		T	T	S
19	100%	Contact ARL to elicit their expectations	1 day	Mon 11/4/02	Mon 11/4/02		T	T	S
7	100%	Contact TRAC Leavenworth/Monterey	2 days	Mon 11/4/02	Tue 11/5/02		T	T	S
9	100%	Functional Analysis	88 days	Mon 10/14/02	Tue 2/11/03		T	T	S
10	100%	What info. F.A. Commanders Need	7 days	Mon 10/14/02	Mon 10/21/02		T	T	S
11	100%	What Decisions F.A. commanders make	7 days	Fri 11/1/02	Mon 11/11/02	10	T	T	S
12	100%	I-O Modeling	7 days	Mon 2/3/03	Tue 2/11/03	11	T	T	S
13	100%	Research Future Applications across disciplines	10 days	Fri 1/10/03	Thu 1/23/03		T	T	S
14	100%	Value Hierarchy	31.5 days	Mon 1/27/03	Tue 3/11/03		T	T	S
15	100%	Trade-offs and Relationships	21 days	Mon 1/27/03	Tue 3/11/03		T	T	S
16	100%	Complete VH	5 days	Mon 1/27/03	Fri 1/31/03		T	T	S
113	100%	Research Capabilities of Technology	16 days	Mon 2/3/03	Mon 2/24/03		T	T	S
114	100%	Benefits to the meteorology community	16 days	Mon 2/3/03	Mon 2/24/03		T	T	S
115	100%	Benefits to maneuver units	16 days	Mon 2/3/03	Mon 2/24/03		T	T	S
116	100%	Benefits to the intelligence community	16 days	Mon 2/3/03	Mon 2/24/03		T	T	S
117	100%	Benefits to the aviation community	16 days	Mon 2/3/03	Mon 2/24/03		T	T	S
118	100%	Benefits to other battlefield systems	16 days	Mon 2/3/03	Mon 2/24/03		T	T	S
119	100%	Investigating benefits that may accrue to other governm	16 days	Mon 2/3/03	Mon 2/24/03		T	T	S
120	100%	Evaluating the vulnerabilities of sensor in a harsh, hostil	11 days	Mon 2/24/03	Mon 3/10/03		T	T	S
121	100%	Environmental Factors	11 days	Mon 2/24/03	Mon 3/10/03		T	T	S
90	100%	Video Production	30 days	Mon 3/17/03	Fri 4/25/03		T	T	S
91	100%	Video/Still Image Capture	202 days	Fri 8/30/02	Fri 6/6/03		T	T	S
22	100%	Update Web Site	212 days	Wed 8/28/02	Wed 6/18/03		T	T	S
45	100%	Update Budget	212 days	Wed 8/28/02	Wed 6/18/03		T	T	S

Task

Split

Progress

Milestone

Summary

Project Summary

External Tasks

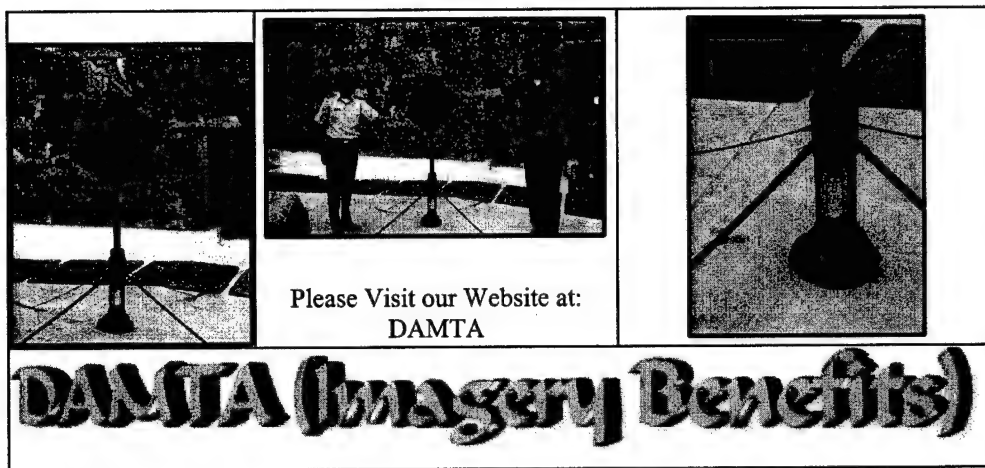
External Milestone

Deadline

Project: DAMTA_benefits

Date: Thu 5/15/03

Appendix B: DAMTA IMAGERY BENEFIT SURVEY



This is a Web-based survey. The information will be used to develop a weather information collection system as part of the Army Future Combat System. Specifically it will assist us in developing and evaluating the benefits of imagery on a weather collection system. Please take the time to fill out the questions below.

The Army Research Laboratory, Battlefield Environment Division, at White Sands Missile Range, New Mexico is currently involved in overseeing the development of a new battlefield intelligence gathering resource, DAMTA (Disposable, Air-droppable, Meteorological Tower Array). The purpose of this effort is to provide the Army with a capability to gather meteorological data from battlefield areas where we have no weather information. DAMTA will consist of multiple small meteorological towers, which will be airdropped over selected battlefield locations by an airborne platform. They will collect and transmit data (i.e., humidity, wind direction, wind speed, temperature, and barometric pressure) for up to 30 days then abandoned. The information will be sent back real-time to operation centers where the data will be analyzed and used for weather reporting and forecasting for tactical units. For our purposes, we are focusing on the benefits of digital imagery (pictures) of the sky and horizon collected by the DAMTA platform. These images would be accessed in the field by clicking icons on a map where the DAMTA platform has been inserted. Each icon would bring up 2 to 3 images of the horizon in different directions. We would appreciate your feedback regarding the functionality and benefits such imagery could bring to a tactical unit.

Questions	Choices
1. Which tactical weather information sources have you used in the past either in training or real-world army missions? (Check all that apply)	Satellite
	Intelligence Assets
	Human Assets (Scout, etc.)
	Sensors
	Robotics (Unmanned Ground Vehicle (UGV))
	Intra-/Inter-net
	Unmanned Aerial Vehicle (UAV)
	Aviation Assets

	Other: Fill-in	
2. Select the two most important pieces of weather information based on the benefits it would provide you as a tactical leader. Please fill-in any other weather information that is important to you.	Most important:	Visibility
		Sky Conditions
		Wind Speed
		Wind Direction
		Altimeter
		Temperature
		Dew Point
	Next most important:	Precipitation
		Visibility
		Sky Conditions
		Wind Speed
		Wind Direction
		Altimeter
		Temperature
Other:	Dew Point	
	Precipitation	
Text (Open Ended)		



Figure 1 - Current Image

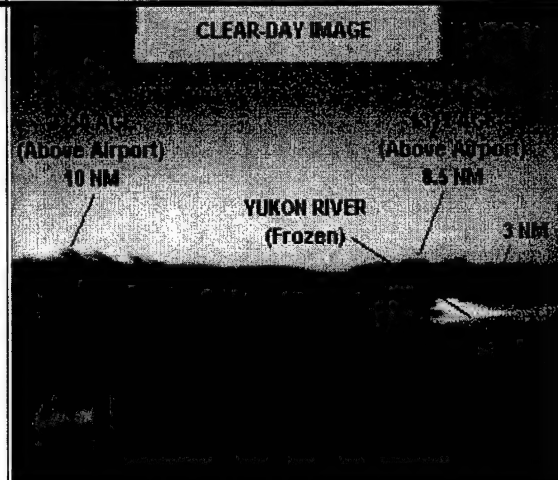


Figure 2 - Clear Day Image

3. Rank order the battlefield functions on the right from most important to least important. Give the highest priority to functions that would be most benefited by the availability of digital images. Assume you are receiving 30-minute-old digital images (Figure 1, above) of locations within your Area of Concern from multiple weather collection systems. Assume that you have a clear-day image of the same view (Figure 2, above) to compare the current image against. Select the drop-down box corresponding to the appropriate number (Number 1 indicates the highest priority and most benefit).

Survivability

Lethality

Mission Planning

Information Gathering

Situational Awareness

Sustainability

Decision-Making

4. Pilots using imagery, as described above, have found that images help greatly to understand sky conditions, visibility, and ground conditions. What information from digital images would be most beneficial to you as a tactical leader on the battlefield? (Check all that

Current ground cover (Vegetation, trees, barren)

Current ground condition (Snow, mud, etc.)

Immediate terrain visualization (Local relief, general condition)

Distant terrain visualization (Mountains, desert)

apply.)	Current visibility (Fog, clear, haze, smoke)
	Current sky condition (Clear of clouds, overcast, type of clouds)
	Current precipitation (Snow, rain)
	Weather effects on light conditions (Dark, bright, dawn, dusk)
5. Select the types of weather information that is important to your branch based on tactical situations that you had in the past?	Visibility
	Sky Conditions
	Wind Speed
	Wind Direction
	Altimeter
	Temperature
	Precipitation
	None

SPECIFIC CAMERA QUESTIONS (SECTION C)
Please answer the following questions regarding capabilities and features of imagery systems on the DAMTA platform.

For the next four questions (6-9), please use the scale below:				
Strongly Agree	Agree	No Opinion or Don't Know	Disagree	Strongly Disagree
1	2	3	4	5

6. Control of the camera in order to possess a PAN (left to right movement) capability is important? (1-5)	1	
	2	
	3	
	4	
	5	
7. Control of the camera in order to possess a TILT (up and down movement) capability is important?	1	
	2	
	3	
	4	
	5	
8. Control of the camera in order to possess a ZOOM (ability to magnify or reduce images) capability important?	1	
	2	
	3	
	4	
	5	
9. What additional features or capabilities would you like to see on a battlefield digital imagery system being used to collect weather information?	Text (Open Ended)	
10. Control of a camera requires increased bandwidth, and increases the probability of mechanical failure and detection by enemy forces; what is the value to you and your unit on control of the camera? Rank order the following scenarios (items a-c). Represent each scenario with a number from 1 to 3 with 1 being the	a. High control by user (Pan, tilt, zoom). High probability of loss of images or control within 30 days.	1
		2
		3
	b. Medium control by	1

<p>most in regards to digital imaging.</p>	<p>Configuration 2: Three cameras with a 50-60 degree field of view for each camera. Cameras are both forward and rear oriented (Figure 4). There is no distinguishable imagery distortion.</p> <p>Configuration 3: One camera with a full 360-degree view capability using mirrors but delivers some distortion to the user.</p>	
<p>13. A weather collection system with imagery would be very valuable to my unit and me? Select 1-5 with 1 being the best.</p>	<p>1-5</p>	
<p>14. How often do you believe that images would need to be updated to be tactically beneficial to you on the battlefield?</p>	<p>Continually (Every several seconds)</p>	
	<p>Every 5 minutes</p>	
	<p>Every 30 minutes</p>	
	<p>Every 1 hour</p>	
	<p>Every 3 hours</p>	
<p>15. Do you feel a weather collection system with imagery would enhance your success on the battlefield?</p>	<p>Yes</p>	
	<p>No</p>	
	<p>Not Sure</p>	
<p>16. How would a weather collection system with imagery best enhance your success on the battlefield?</p>	<p>Text (Open Ended)</p>	
<p>17. Do you have any other feedback you would like to share with us regarding a weather collection system or the benefits of imagery?</p>	<p>Text (Open Ended)</p>	

Appendix C: Cold Test Plan

DIGITAL IMAGERY EQUIPMENT TEST PLAN FOR COLD REGIONS TEST CENTER, FORT GREELY, AK (21 JAN – 24 FEB 03)

Client Organization: Engineering Management Program, Department of Systems Engineering, United States Military Academy, West Point, NY.

Point of Contact:

Name:	Address:	Phone:	Other / Email:
LTC James M. Buckingham	Department of Systems Engineering United States Military Academy West Point, NY 10996	AV 688-5181 Comm. (845) 938-5181	James.buckingham@usma.edu

Other Research Team Members:

MAJ Greg Lamm
Cadet Chris Green
Cadet David Bunt
Cadet Jacob Bailey

Background: LTC James Buckingham is an Assistant Professor in the Department of Systems Engineering at the United States Military Academy. His responsibilities include research, which supports Army needs. He is currently working with a 5 person research group on aspects of a project entitled "Disposable, Air droppable, Meteorological Tower Array" (DAMTA) in support of the Army Research Laboratories (ARL) at White Sands Missile Range, NM.

The ARL Battlefield Environment Division, at White Sands Missile Range, New Mexico is currently involved in overseeing the development of a new battlefield intelligence gathering resource called DAMTA. The purpose of this effort is to provide the Army with a capability to gather meteorological data from battlefield areas that are data sparse. This data is required in order to enhance the accuracy of the Battlescale Forecast Model, as used in the Integrated Meteorological System (IMETS). The IMETS is the provider of meteorological information for the fielded Army.

The DAMTA will consist of multiple individual meteorological towers which will be dispersed over selected battlefield locations by an airborne platform. The towers will be capable of self-erecting to the vertical after being dropped from a moving aircraft at no less than 2000 feet and at speeds up to 120 knots. They will collect and transmit data for up to 30 days.

These towers, once deployed, will communicate collected information to a central node (tower) which will in turn provide data to the IMETS and ultimately to the individual users. The towers will be of two varieties. Type I towers will have a fixed set of meteorological sensors and Type II towers will have the same sensors as well as the capability to add up to five additional

ones. The Type I sensor set will measure wind speed and direction, temperature, humidity and barometric pressure. The Type II set may also include sensors for rain rate, precipitation amount, ground moisture, vertical wind and digital imagery. The DAMTA project encourages the use of off-the-shelf technology. Digital imagery in particular is the focus of LTC Buckingham's research as it provides valuable information not available through other sensors and yet highly desirable on the battlefield.

LTC Buckingham submitted a proposal through a program called University Partnering for Operational Support (UPOS) to research, test, analyze and recommend existing off-the-shelf imagery products that could be integrated with the DAMTA platform to provide near real-time images of the sky and horizon for meteorological purposes on the battlefield.

To date, the research group has researched and purchased several competing imagery sensors (cameras) to analyze and test. An important part of this analysis includes environmental testing in both cold and hot/tropical environments.

Purpose of the Test – The purpose of this test is to determine the low temperature limitations and operational effects on several camera systems to assist in the analysis and eventual recommendation of the best off-the-shelf system to recommend for integration with the DAMTA.

Conduct of the Test – The test will be conducted in two phases as described below. The first phase will require one day of setup and one day in the cold chamber at Fort Greely. It will require the presence of the researchers and will be completed by the end of the second day. The second phase will include setting up hardware at the Bolio Lake facility. The hardware will be tested to ensure it is functioning properly and will be left in place for approximately 30 days. The conduct of the test will be monitored remotely by the researchers from their home base in New York. At the conclusion of the test, the researchers will return to Fort Greely to remove the hardware. The two phases are described in detail below.

Phase 1 – Cold Chamber Test

Date: 21-22 Jan 03. 21 Jan will be used to set up equipment in the cold chamber. The cold chamber test will be conducted on 22 Jan.

Location: Cold chamber facility, Fort Greely, AK.

Description of Test:

21 Jan Setup: Four to eight small video cameras will be positioned inside the cold chamber on small camera mounts affixed to a platform. Cameras will be oriented and focused on an optical test pattern on the far wall of the chamber. Cameras will be powered by a 12VDC source located outside the chamber and connected by 18/2 power wire. Cameras will be connected via RG59 coax cable to a switcher and monitors located outside the chamber. Additionally, the cameras will be connected to a laptop with video capture capability to grab and save images during the test.

22 Jan Test: The cold chamber will be initially stabilized at 20 degrees F and camera operation will be determined. The chamber temperature will then be lowered in 10 degree increments to - 50 F and the camera's operation tested at each new temperature. Hardware will be allowed sufficient time to cold soak prior to conducting each operational test at the new temperature. Equipment will be disassembled and removed from the test chamber at the end of the day.

Equipment Required:

Item of Equipment	Provided By:		Comments
	Research Team	CRTC	
Cameras	X		
Coax Cable	X		
Power Cable	X		
Switcher	X		
12VDC Power Source	X		
Camera Mounts	X		
Table for Stand		X	Need a table approximately 4 feet long on which to place the camera platform.
Laptop	X		
Video Monitor		X	Two monitors that will accept BNC connectors and NTSC signal as input.
Dimmer		X	Request you install a dimmer switch or some method of allowing us to dim the lights in the chamber to test optical quality in low light conditions at reduced temperatures.
120 VAC Power – multiple outlets		X	Need access to standard AC power for monitor, laptop, switcher, 12VDC power box, etc.
Technician		X	To assist with initial setup on 21 Jan and with initial operation of the chamber on 22 Jan.
Extension cords		X	Several extension cords to allow positioning of equipment as required.

Phase II – Bolio Lake Extended Test

Date: 23Jan - 24 Feb 03. 23 Jan will be used to set up equipment at the Bolio Lake facility. The actual test will be started and initially observed on 24 Jan. Equipment will be removed on/about 24 Feb.

Location: Bolio Lake Facility, Fort Greely, AK. Specifically, we would like to set up hardware either on the roof, or in a location that will allow a view of the sky and horizon throughout the test. Location must have direct access to a network connection. The need for and use of the network has already been coordinated with Mr. Eric Anderson.

Description of Test:

23 Jan Setup: Four to eight small video cameras will be positioned outside approximately 3-4 feet above the surface of the ground (or roof). Cameras will be oriented and focused at an infinite distance toward the horizon and sky. Cameras will be powered by a 12VDC source located inside the test facility and connected via 18/2 power wire. Cameras will be connected via RG59 coax cable to two network video servers located inside the test facility. Each network video server will be connected to the network with IP addresses of 140.32.128.50 and 140.32.128.51 respectively as previously coordinated with Mr. Eric Anderson at Bolio. Additionally, the cameras will be connected to a laptop with video capture capability to grab and save images during the test.

24 Jan Test: This day will be used primarily to ensure that the network video servers are operating properly. Initially we will need access to a networked computer, or we will need to tie the research group's laptop into a network connection to access and test the servers. We would prefer the latter (temporary network connection for the laptop). Tests will be conducted to ensure that video images can be obtained through the network for each of the cameras being tested. This day will also be used to instruct a CRTC technician on the basic setup of the hardware so that he/she can assist with minor changes, exchanges of cameras or repairs during the test. Once we have ascertained that the servers are working correctly, the research team will be at liberty to leave the test site. The equipment will then remain in place until approximately 24 Feb 03 when someone from the team will return to evaluate the status of the equipment, terminate the test, and remove the hardware from the site. At this point the test will be concluded.

Equipment/Resources Required:

Item of Equipment	Provided By:		Comments
	Research Team	CRTC	
Cameras	X		
Coax Cable	X		
Power Cable	X		
Switcher	X		To initially determine if cameras are oriented and setup properly.
12VDC Power Source	X		
Camera Mounts	X		
2 Network Video Servers	X		
Laptop	X		
Video Monitor		X	Large monitor that will accept BNC connector and NTSC signal as input. This will be used to ensure that camera orientation and setup is correct.
120 VAC Power – multiple outlets		X	Need access to standard AC power for monitor, laptop, switcher, 12VDC power box, etc.
Technician		X	To assist with initial setup of hardware on 23 Jan.
Network Operator		X	To assist with network connections, setting IP on video servers and testing video servers on 24 Jan.
Outside Test Location		X	Need a location outside to setup the test hardware. Prefer to set it up on the roof

			where it will be undisturbed and will have a clear view of the sky and horizon.
Inside Hardware Location		X	Need a location inside the test facility to setup and leave a small amount of test hardware. A 6 square foot table would be sufficient. (3' x 2').
Platform/table		X	Need something to secure the camera test platform to which will raise the platform off the ground/roof 3-4 feet.
Platform/table		X	Need a location and a table to set hardware on inside the facility for the duration of the 30 day test.
Two 10 BaseT cables to connect video servers to network.		X	
Extension cords		X	Several extension cords to allow positioning of equipment as required.

Other Issues

Agreements to Date: I have been in communication with Mr. Dan Coakley via e-mail regarding this test. I also met with LTC Chris Miller and Mr. Mike Etzinger in June 2002 regarding my intent to conduct this test. Initial communication from CRTC is that we will agree to pay \$4,500 to utilize the services and resources of the CRTC for the test as described herein. E-mail from Dan Coakley is reproduced below.

Sir,

The estimate I completed totaled \$4,500.00. This includes the chamber costs with a technician, an individual to help set-up your cameras at the Bolio Lake facility and an individual to ensure your equipment is there and still operating after you leave. It also includes 5 hours if needed for CRTC to help diagnose any problems on this end after your departure. Dan

Daniel Coakley
Project Officer
Cold Regions Test Center
DSN: 317-873-4801 FAX: 1989
COMM: 907-873-4801

Appendix D: Hot/Tropical Test Plan

DIGITAL IMAGERY EQUIPMENT TEST PLAN FOR DIRECTOR, TROPIC REGIONS TEST CENTER US ARMY YUMA PROVING GROUND, AZ (18 MAR 03 – 15 APR 03)

Client Organization: Engineering Management Program, Department of Systems Engineering, United States Military Academy, West Point, NY.

Point of Contact:

Name:	Address:	Phone:	Other / Email:
LTC James M. Buckingham	Department of Systems Engineering United States Military Academy West Point, NY 10996	AV 688-5181 Comm. (845) 938-5181	James.buckingham@usma.edu

Other Research Team Members:

MAJ Greg Lamm
Cadet Chris Green
Cadet David Bunt
Cadet Jacob Bailey

Background: LTC James Buckingham is an Assistant Professor in the Department of Systems Engineering at the United States Military Academy. His responsibilities include research, which supports Army needs. He is currently working with a 5 person research group on aspects of a project entitled "Disposable, Air droppable, Meteorological Tower Array" (DAMTA) in support of the Army Research Laboratories (ARL) at White Sands Missile Range, NM.

The ARL Battlefield Environment Division, at White Sands Missile Range, New Mexico is currently involved in overseeing the development of a new battlefield intelligence gathering resource called DAMTA. The purpose of this effort is to provide the Army with a capability to gather meteorological data from battlefield areas that are data sparse. This data is required in order to enhance the accuracy of the Battlescale Forecast Model, as used in the Integrated Meteorological System (IMETS). The IMETS is the provider of meteorological information for the fielded Army.

The DAMTA will consist of multiple individual meteorological towers which will be dispersed over selected battlefield locations by an airborne platform. The towers will be capable of self-erecting to the vertical after being dropped from a moving aircraft at no less than 2000 feet and at speeds up to 120 knots. They will collect and transmit data for up to 30 days.

These towers, once deployed, will communicate collected information to a central node (tower) which will in turn provide data to the IMETS and ultimately to the individual users. The towers will be of two varieties. Type I towers will have a fixed set of meteorological sensors and

Type II towers will have the same sensors as well as the capability to add up to five additional ones. The Type I sensor set will measure wind speed and direction, temperature, humidity and barometric pressure. The Type II set may also include sensors for rain rate, precipitation amount, ground moisture, vertical wind and digital imagery. The DAMTA project encourages the use of off-the-shelf technology. Digital imagery in particular is the focus of LTC Buckingham's research as it provides valuable information not available through other sensors and yet highly desirable on the battlefield.

LTC Buckingham submitted a proposal through a program called University Partnering for Operational Support (UPOS) to research, test, analyze and recommend existing off-the-shelf imagery products that could be integrated with the DAMTA platform to provide near real-time images of the sky and horizon for meteorological purposes on the battlefield.

To date, the research group has researched and purchased several competing imagery sensors (cameras) to analyze and test. An important part of this analysis includes environmental testing in both cold and hot/tropical environments. The cold weather testing is currently ongoing and will be complete on 28 Feb 03.

Purpose of the Test – The purpose of this test is to determine tropical and hot weather limitations and operational effects on several camera systems to assist in the analysis and eventual recommendation of the best off-the-shelf system to recommend for integration with the DAMTA.

Conduct of the Test –

a. General - The test will be conducted as follows. LTC Buckingham will arrive on 17 Mar 03. He will spend 18 – 20 Mar 03 setting up and testing equipment at the Ft. Sherman test site. Setup and testing should be able to be completed within a day however, three days have been scheduled to offset any unforeseen circumstances. He will then leave the equipment in place and return to New York on 23 Mar. The equipment will be remotely monitored from New York for the next 26 days. He will return to the test site on 15 Apr 03 to remove the equipment and complete the test.

b. Specific – A detailed description of the schedule and the test are described below.

17 Mar – LTC Buckingham arrives in Panama and proceeds to Hotel El Panama

18 – 20 Mar – LTC Buckingham sets up and tests equipment which is to be left at the test site for 26 days. All of the test equipment will fit inside of two footlocker sized containers which will arrive with LTC Buckingham. Eight small video cameras will be mounted outside preferably with an open view toward distant terrain and the horizon. Two test stands with four cameras each will be used in the test. The test stands will need to be mounted on a couple of saw horses or a table which is approximately 42 inches off of the ground. Request that the test site provide the saw horses or table. The test stands can be clamped or screwed to the saw horses or table for the test. Figures 1 and 2 below show the test stands, saw horses and cameras used for the cold weather test in Alaska. The same basic setup will be used in Panama.



Figure 1 – Saw Horses with Camera Test Stands and Video Cameras to be tested



Figure 2 –Camera Test Stands and Video Cameras to be tested

Cameras will be powered by a 12VDC source located inside the test facility and connected via 18/2 power wire. Cameras will be connected via RG59 coax cable to two network video servers located inside the test facility. The video servers will be connected to modems, and the modems connected to the two telephone drops in the test facility. Standard 110/120 Volt AC power will be required to power the 12VDC power supply, the network camera servers and the external modems. An uninterrupted Power Supply is desirable to protect the system during operation for the 26 day test. Figure 3 below shows the equipment used in the cold weather test. The UPS is on

the bottom. The 12VDC power supply is on top of the UPS. The two network camera servers sit on top of the power supply. There is an ethernet hub on top of the right-most camera server. However, the ethernet hub will not be used in the tropical test since there is no network connection. Instead, each network camera server will have it's own modem. All the equipment below will be furnished by LTC Buckingham with the exception of the UPS. Figure 4 below shows a graphic of the hardware setup.

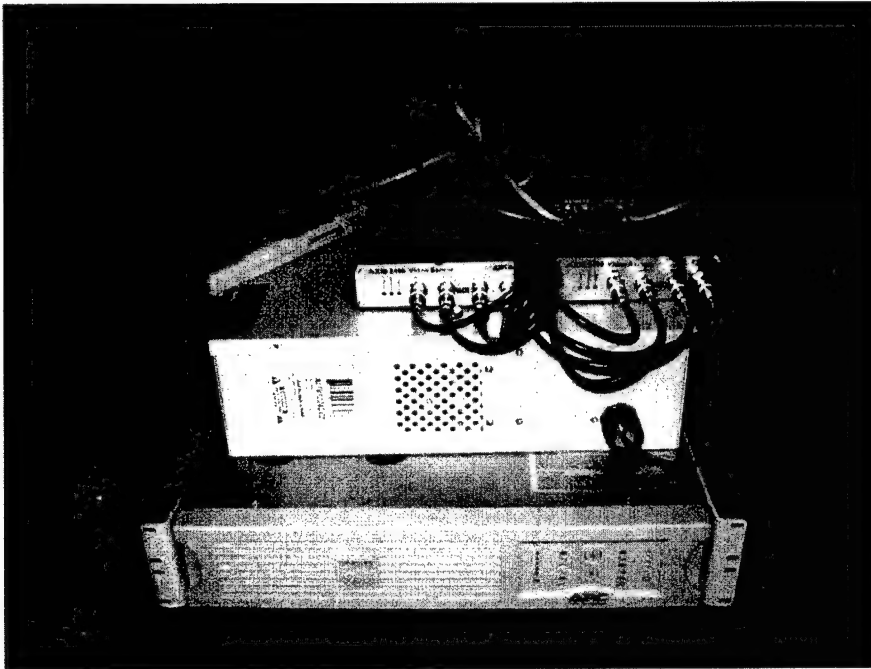


Figure 3 – UPS, 12VDC Power Supply, Network Camera Servers and Ethernet Hub

Once the cameras and hardware are set up, a test will be conducted to ensure that the camera servers and images can be accessed through the modems. This will require the use of a third telephone line from which to call the other two lines connected to the modems. Only two dedicated phone lines are required for the 26 day test. The third line will be used occasionally during 18-20 Mar to ensure the equipment is working properly. If there is no third line available, then the two lines may be used to test each other. Once proper connections are confirmed, the equipment will be left on site and LTC Buckingham will return to New York. The research team will access the camera images from New York through a direct long distance connection and download images throughout the test. The researchers will require little to no assistance during the conduct of the test except perhaps to reorient cameras, clean off lenses or troubleshoot coax or power lines if there is trouble getting images.

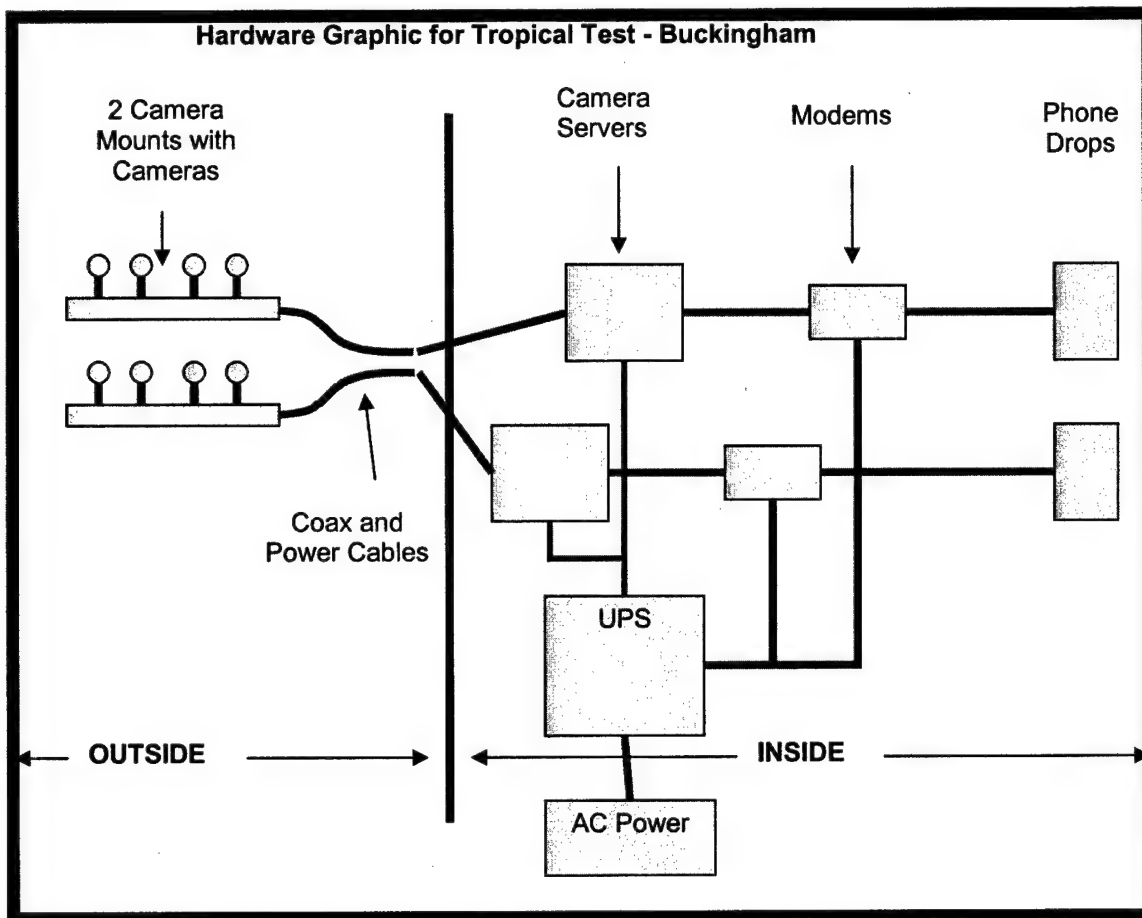


Figure 4 – Graphic of Hardware Setup for Tropical Test

14 Apr 03 – LTC Buckingham returns to Panama

15-16 Apr 03 – Equipment is removed from the test site. Test is complete.

17 Apr 03 – LTC Buckingham returns to New York.

c. Equipment Required – The equipment required for the test is listed in the table below. It also establishes who will provide each resource. Items with an X under the TRTC listing should be provided by the test center.

Item of Equipment	Provided By:		Comments
	Research Team	CRTC	
Cameras	X		
Coax Cable	X		
Power Cable	X		
Switcher	X		To initially determine if cameras are oriented and setup properly.
12VDC Power Source	X		
Camera Mounts	X		1 x 4 x 24 to which cameras are attached.
2 Network Video Servers	X		
2 Modems	X		
Laptop	X		For initial testing
Telephone Drops		X	Need two standard active telephone drops with phone numbers to connect modems to
UPS		X	Need 1 uninterrupted power supply for the 26-day test.
Video Monitor		X	Video monitor that will accept BNC connector and NTSC signal as input. This will be used to ensure that camera orientation and setup is correct.
120 VAC Power – multiple outlets		X	Need access to standard AC power for monitor, laptop, switcher, 12VDC power box, etc.
Technician		X	To assist with initial setup of hardware on 18-20 Jan. I do not anticipate the need for detailed technician support. Primarily I need someone to assist with showing me where to set up the hardware, where the phone drops are etc.

Outside Test Location		X	Need a location outside to setup the test hardware. Prefer to set it up where it will be undisturbed and will have a clear view of the sky and horizon.
Inside Hardware Location		X	Need a location inside to setup and leave a small amount of test hardware. A 6 square foot table would be sufficient. (3' x 2').
2 Saw Horses or Tables		X	Need something to secure the camera test platform to which will raise the platform off the ground approximately 36 – 48 inches.
Platform/table		X	Need a location and a table to set

			hardware on inside the facility for the duration of the 26 day test.
Extension cords		X	Several extension cords to allow positioning of equipment as required.

Additional Information

Please contact LTC Buckingham at the numbers on the first page for any questions regarding this test plan.

In addition please provide an estimate of the test cost and some breakdown showing how the estimate was derived.

Appendix E: Compact Disk (CD) Information

Enclosed on the CD in the back of the book are two files listed below:

- *DAMTA_Final_Tech_Report2003*: Final Technical Report
- *DAMTA_Final_Brief*: Final Brief for DAMTA

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